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OCTOBER-NOVEMBER 1943

STRUCTURE AND ORIGIN OF BLACK HILLS PRE-CAMBRIAN GRANITE DOMES — J. J. RUNNER — 431

MARINE TOPOGRAPHY OF THE CAPE MAY FORMATION — PAUL MACCLINTOCK — 458

ENVIRONMENTAL SIGNIFICANCE OF A SMALL DEPOSIT IN THE TEXAS PERMIAN — WILLIAM F. READ — 473

RECENT DEPOSITS OF VESICULATED MUD ALONG SOUTHWESTERN OHIO STREAMS — ROBERT H. GRIFFIN AND ROBERT E. SHANKLIN — 488

SOME WRONG WORDS — CHESTER W. WASHBURNE — 495

GERARD DE GEER, 1858–1943 — ROLLIN T. CHAMBERLIN — 498

REVIEWS

Seismology, PERRY BYERLY (R. T. C.) — 499

The Floor of the Ocean: New Light on Old Mysteries, REGINALD ALDWORTH DALY (Gordon Rittenhouse) — 500

Structural Geology, MARLAND P. BILLINGS (R. T. C.) — 500

Scott County Geology, Tests, Fossils, HARLAN RICHARD BERGQUIST and THOMAS EDWIN MCCUTCHEON (Irving B. Hamilton) — 501

Ore Deposits as Related to Structural Features, W. H. NEWHOUSE (ed.) (R. T. C.) — 501

Proceedings of the Eighth American Scientific Congress, Vol. IV: *Geological Sciences* (R. T. C.) — 502

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STRUCTURE AND ORIGIN OF BLACK HILLS PRE-CAMBRIAN GRANITE DOMES

J. J. RUNNER
University of Iowa

ABSTRACT

The pre-Cambrian granite masses of the southern Black Hills are regarded as protrusions through the schistose sedimentary cover from a batholithic mass below. The granites of the Harney Peak area are a composite of many sills, tongues, dikes, and irregular masses of various compositions and ages. Within the area are many xenoliths of sedimentary rocks which in the central part are composed of metalimestone and amphibolite. The bedding planes and the axial planes of the isoclinal folds in the sedimentary inclusions in the interior dip outward from the central axial region and form a well-defined xenolith dome. The growth of the dome is believed to have been from the center outward by marginal intrusion on the border of a laccolith-like structure rather than by outward spread from central intrusion. As the structure increased in size, marginal dips steepened. Xenoliths were isolated largely by cross-cutting masses intersecting concordant injections and for the most part were never completely engulfed in liquid magma, so that there was little or no downward stoping.

The formation of the Harney Peak dome was preceded in the area by overthrust faulting and recumbent folding and accompanied by the production of vertical faults near the margin of the granite mass, probably by the force of intrusion.

INTRODUCTION

Granite and related pegmatites occur rather widely distributed throughout the southern one-third of the pre-Cambrian area of the Black Hills of South Dakota. Within this area there are two smaller ones in which the granites form well-defined domes in the schistose sedimentary rocks. The larger of the two domes centers around a point approximately 3 miles southeast of Harney Peak and may well be called the "Harney Peak dome" (Figs. 1 and 2). The second lies some 10 miles west of Harney Peak in the region of Bear Mountain and will be referred to as the "Bear Mountain dome" (Figs. 1 and 3).

There is some evidence to indicate that the granite masses in Ts. 3 and 4 S., R. 6 E., and Ts. 4 and 5 S., R. 5 E., may lie near the western portion of still other domes.

The similarity in petrography and age of the granites of the southern hills to those of the Nigger Hill and Whitewood Peak areas of the northern Black Hills makes probable the view that all are projections from the upper surface of a still larger batholithic mass which may very properly be referred to as the "Black Hills pre-Cambrian batholith."

It is not the purpose of this paper to discuss the internal-structure features of the granites and pegmatites. Dr. Robert Balk[1] has presented the results of his findings during a few weeks' field

[1] "Inclusions and Foliation of the Harney Peak Granite, Black Hills, South Dakota," *Jour. Geol.*, Vol. XXXIX (1931), pp. 736–48.

work in the Harney Peak area. His conclusion that the granite forms a structural dome is apparently based entirely upon his observation that "the regional dip and strike is lost completely in a perfect cupola in the core of which the granite outcrops." The cupola referred to by Balk is, according to his interpretation, outlined by the schists bordering the granite and is not the one shown in Figures 1 and 2. Balk reported no dome or arch of flow layers or flow lines, no fan of cross joints, and no preferred orientation of inclusions except in a few places on the western border of the granite.

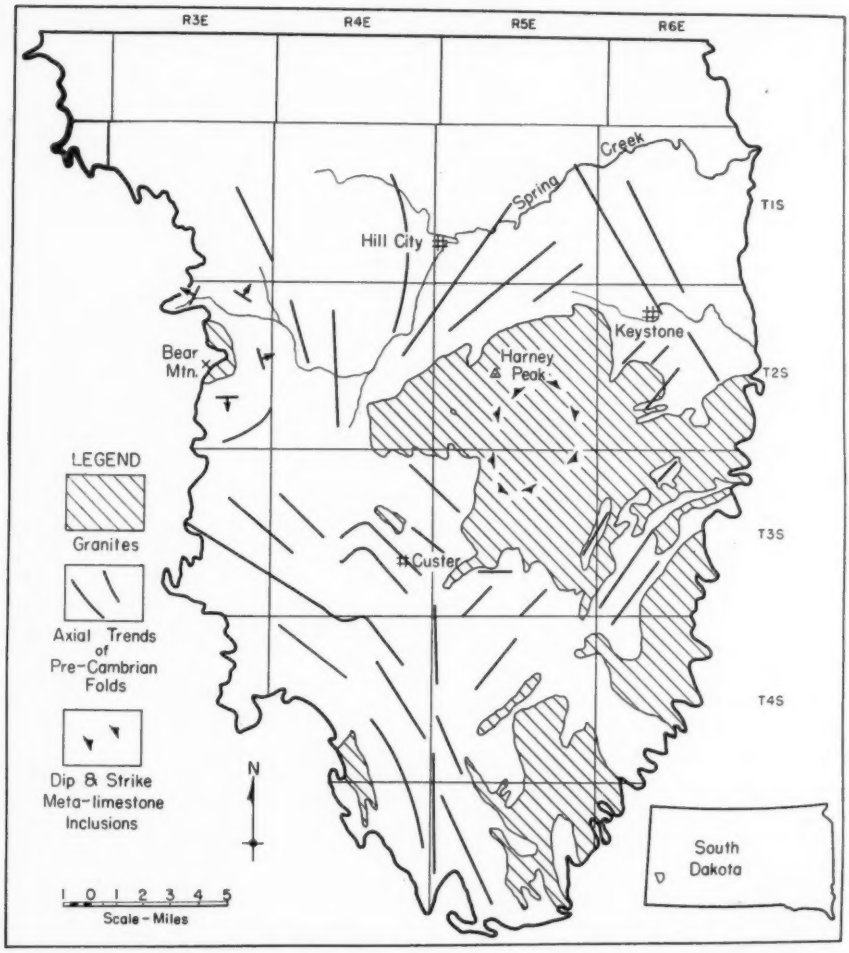

FIG. 1.—Generalized map showing trend of pre-Cambrian folds in southern Black Hills in relation to occurrences of granite. Outlines of granite areas modified after *U.S. Geol. Surv. Folio No. 219*.

In this paper data are presented that contribute to a better understanding of the structure and mechanics of intrusion of the granites and pegmatites of the Harney Peak region than have been

gained from studies of the internal structure of the granites. These data include regional stratigraphy and structure, the occurrence and interrelationships of individual granite masses, and the stratigraphy, orientation, distribution, and petrography of metasedimentary inclusions in the granite.

The pre-Cambrian area of the southern Black Hills is of especial interest to students of petrology and structure, since it furnishes a nearly horizontal section through at least two domes and several irregular stocks at the top of a larger batholith. If magmas rise during batholithic emplacement, then every level within a batholith represents what at one stage of intrusion was a roof. Erosion has transected various batholiths to different levels. The phenomena revealed in bath-

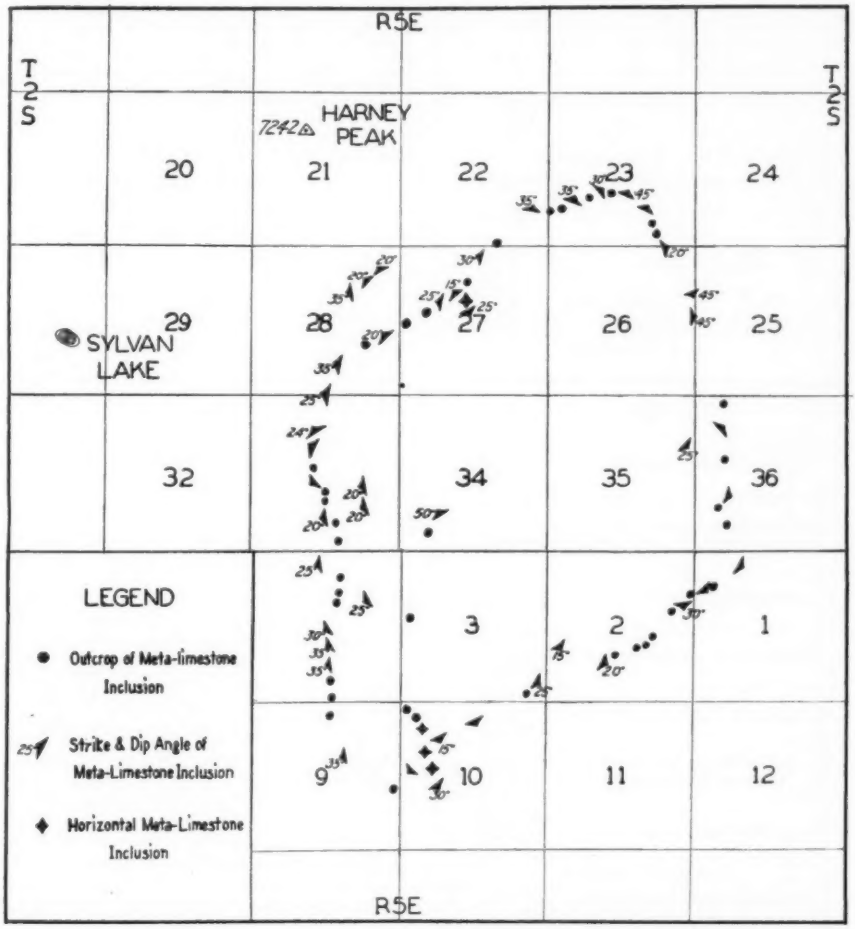

FIG. 2.—Map showing distribution and orientation of the metalimestone inclusions in the Harney Peak granite.

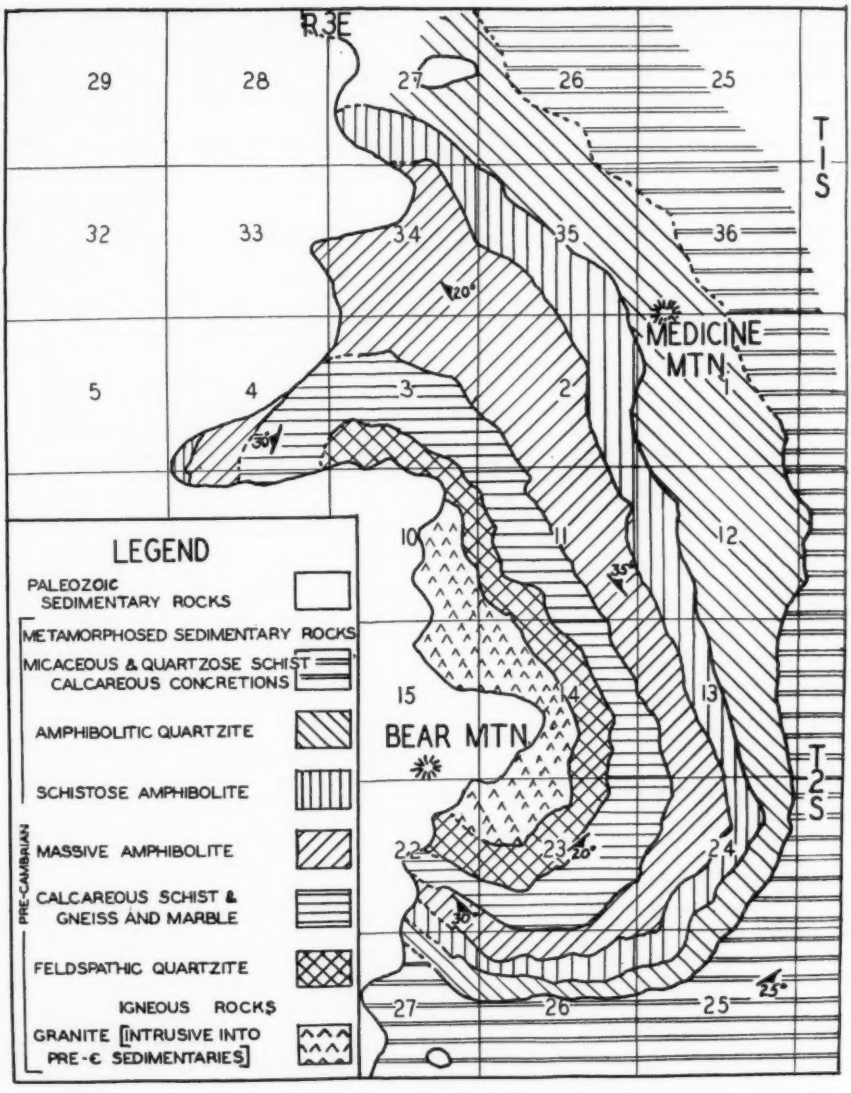

FIG. 3.—Geological map of the Bear Mountain dome

oliths whose upper levels only are exposed may be taken as characteristics of the early stages of others whose intrusion mechanics were essentially the same. Deeper levels of erosion, in turn, reveal phenomena characteristic of successively later stages of intrusion. The study of a sufficient number of levels revealed by different batholiths may in time reveal the complete intrusional history for each separate type of batholith. Intrusion mechanics of one stage of a certain batholith should not be interpreted as typical of another stage or of other intrusives in which pressure, temperature, and composition of magma and lithology and structure of invaded rocks were different. It is important, therefore, to obtain as many data concerning these physical and chemical factors as possible and to determine the stage of intrusion so that the information may be classified in its proper relationship to that in other cases.

HISTORICAL SUMMARY

After studying the field relations of granite and schists in the Harney Peak region of the Black Hills, C. R. Van Hise,[2] Sidney Paige,[3] and Balk[4] reached the following judgments:

1. The main granite area is surrounded by a cupola of schist whose strikes are roughly parallel to the granite border.
2. The Harney Peak granite came into its present position in the main by distention of the older rock body under great pressure.
3. The rocks into which the granite was intruded had been isoclinally folded previously and possessed flow cleavage.
4. Structures produced by the intrusion of the granite were superimposed upon and partially obliterated previously existing structures.
5. Stoping and assimilation by the granite were not important processes.[5]

In addition to the above, Paige[6] made the following generalizations: Many fragments of schist have been so completely permeated with liquid magma that only an outline of the fragment remains. The granitic magma was a mobile low-temperature one containing an abundance of mineralizers. The forms of the intrusive bodies are different in the brittle quartzose rocks and the plastic schistose ones. In the latter the magma invariably followed the paths of easiest ingress, the structural planes, while in the former the dikes and masses do not generally follow bedding planes but nearly everywhere cut across them. The sedimentary rock is broken into numberless fragments that are enmeshed within the intrusive mass, stratigraphic sequence is destroyed, and blocks of strata have been uplifted and eroded away or have sunk far below the surface.

Balk, in the text of his paper and on his geologic map, indicates that a parallelism exists between dips and strikes of inclusions near the border of the granite and those in the surrounding schists but that there is a notable lack of parallelism of inclusions farther within the granite with the border of the schist cupola. He implied that the granite advanced as a "large mass" in which xenoliths were oriented by "distention and expansion of the central portion of the cupola." He concluded from what he realized were rather meager data that the "granite seems to have expanded laterally more readily than upward."

In regard to the orientation of inclusions, Balk states:

> . . . . the individual fragments have moved in subhorizontal directions. Since these planes

[2] "The Pre-Cambrian Rocks of the Black Hills," *Bull. Geol. Soc. Amer.*, Vol. I (1890), pp. 203–44.

[3] N. H. Darton and Sidney Paige, "Central Black Hills," *U.S. Geol. Surv. Folio No. 219* (1925).

[4] *Op. cit.*

[5] By implication in the case of Van Hise.

[6] *Op. cit.*

of movements grade marginally into the cupola of the wall rock, it must be the excessive distention and expansion of the central portion of the cupola which has led to their present position. The picture resembles somewhat that of cakes of ice on the surface of agitated water. If suddenly fixed in their position, each cake would be found in subhorizontal position but dipping in random directions.[7]

Both Paige and Balk regarded foliation of the granite as an important characteristic. Paige stated that the foliation which he calls "layering" "dips outward with the dip of the schists and becomes flatter as it approaches the summit of the mass." He attributed it to the "pressure of intrusion." Balk, on the other hand, after studying and mapping flow layers, inclusions, and their orientation, recognized no schlieren domes or arches, although recognizing a schist cupola.

Paige explained the banding in the granite as due in part to relict structures of impregnated and granitized sediment. Balk, on the other hand, states that "in all such cases that have come to the writer's attention" the directions of mineral parallelism of inclusions and those in the granite make high angles with each other. He concluded, therefore, that the banding is largely a function of "magma movement."

Paige recognized granite of fine and coarse texture but made no important age distinction between the two. Balk recognized "granite dikes, intruded into slightly older granite masses."

Ernst and Hans Cloos[8] state that the elongation of the Harney Peak batholith parallels the axis of Tertiary folding in the Black Hills.

Subsequent to the publication of the Black Hills folio and antedating the paper by Balk, Runner[9] presented the view that the granites invaded sedimentary rocks modified by gentle folds only. The concept of intrusions of magma in successive small increments with little rotation or sinking of xenoliths was advanced. In a subsequent publication the same author[10] concluded, as had Van Hise, Paige, and Balk, that the sedimentary rocks had been intricately folded and possessed flow cleavage before the granitic penetration. In the same paper evidence was presented that there had been at least two granitic invasions in that region.

REGIONAL STRATIGRAPHY

The pre-Cambrian metasedimentary rocks of the southern Black Hills may be divided into three and possibly four lithologic groups. These lithologic groups, furthermore, probably constitute stratigraphic divisions, although the precise relationships are as yet somewhat uncertain.

Group 1 is believed to be the oldest. It comprises largely quartzites and mica-sillimanite schists. It contains very little calcareous matter either as beds or as concretions and very little, if any, sedimentary amphibolite. Group 1 occupies a large part of Ts. 4 and 5 S., R. 5 E., and Ts. 3 and 4 S., R. 6 E.

Group 2 is probably next in age. It contains thin quartzites, calcareous schist and marble, sedimentary amphibolite, and mica-sillimanite schist. It is found in beds surrounding the Bear Mountain granite and as inclusions in the Harney Peak granite.

[7] *Op. cit.*

[8] "Pre-Cambrian Structure of the Beartooth, Big Horn and Black Hills Uplifts and Its Coincidence with Tertiary Uplifting," *Proc. Geol. Soc. Amer. for 1933* (1934), p. 56.

[9] "Intrusion Mechanics of the Harney Peak Batholithic Granite," *Bull. Geol. Soc. Amer.*, Vol. XXXIX (1928), p. 186.

[10] Runner and R. G. Hamilton, "Metamorphosed Calcareous Concretions and Their Metamorphic and Structural Significance," *Amer. Jour. Sci.*, Vol. XXVIII (1934), pp. 51–65.

Group 3 consists of micaceous schists, thin quartzites, impure calcareous beds, and much sedimentary amphibolite. It is possible that group 3 correlates with group 2. It outcrops throughout T. 1 S. and the northern part of T. 2 S., R. 6 E.

Group 4 comprises thick formations of massive quartzose siltstones interbedded with micaceous schist, both containing calcareous concretions; thin impure limestone beds; sedimentary amphibolites; and thin quartzites. Group 4 occupies areas southwest and south of Keystone, also considerable parts of Ts. 1 and 2 S., Rs. 4 and 5 E., and Ts. 3, 4, and 5 S., Rs. 3 and 4 E.

GENERALIZED REGIONAL PRE-CAMBRIAN STRUCTURE

The pre-Cambrian metasedimentary rocks of the southern Black Hills were isoclinally folded, rendered schistose, faulted, and intruded by granite during pre-Cambrian times. Knowledge of the detailed features of many of the folds and faults in the region is as yet incomplete, and so they do not appear on the map in Figure 1.

FAULTS

The major fault is a great overthrust from the southeast. The trace of this fault extends from the southwestern part of T. 5 S., R. 5. E., northward to Sec. 31, T. 3 S., R. 5 E., where it turns northeastward. It is offset about 1 mile to the southeast in Sec. 28, T. 3 S., R. 5 E., and again offset nearly 2 miles in the same direction in Sec. 23, T. 3 S., R. 5 E., by two northwesterly striking cross faults. From the southern part of Sec. 24, T. 3 S., R. 5 E., it runs generally northeastward to a point near the center of the south half of T. 2 S., R. 6 E., where it is again offset to the southeast several miles by another cross fault. This cross fault extends from this point northwestward past Keystone.

There is considerable evidence for a northeast-southwest fault along Spring Creek near Hill City and another that strikes east-west across the southern part of T. 2 S., R. 4 E. Several small faults have been noted near Custer. Both overthrust and cross faults are pregranite in age and later than much of the folding and schistosity. Their possible relationships to intrusion will be discussed after a brief description of the principal fold patterns.

FOLDS

Folding in the quartzites and schists of the overthrust block in Ts. 3, 4, and 5 S., Rs. 5 and 6 E., is very complex. Some of it resembles imbricate structures tilted on edge or a series of vertically pitching drag folds on the limbs of major folds. Where granites have been intruded into these folded masses there are many points where discordant relations exist. This is apparently the source of Paige's observation[11] that the "form of the intrusive body is different in the brittle quartzites and the more plastic schists." He states that "in the brittle rocks the dikes and masses do not generally follow the bedding planes of the invaded rock." It seems more likely that this condition is due to the complex structures of the quartzites rather than to the physical properties of the rocks.

The trends of folds within the overthrust block and near its front are roughly parallel to the trace of the fault. In T. 3 S., Rs. 5 and 6 E., the trends are northeastward, while in the western part of Ts. 4 and 5 S., R. 5 E., their directions are nearly north-south. The strikes of fold axes in Ts. 4 and 5 S., R. 4 E., bend to approximate parallelism to the

[11] *Op. cit.*

fault trace as they approach it. The major axis of the dome outlined by metalimestone inclusions in the Harney Peak granite (Fig. 1) and the trends of folds in two belts of several miles' width—one on the southeast and one on the northwest of the dome—are also roughly parallel to the strike of the overthrust fault.

STRUCTURAL RELATIONS OF THE GRANITES AND METASEDIMENTS

Balk[12] (Fig. 1) used long strike lines to designate the "general strike . . . . of the cupola of schist." These lines, which are approximately parallel to the granite contact on all but the southern side, might be interpreted as indicating either that a single schistose stratigraphic unit follows the contact or that the flow-cleavage planes strike parallel to the contact. As a matter of fact, the granite border intersects both bedding and schistosity at sharper angles than Balk's map indicates, especially on the northeast and southwest.

The main granite-schist contact of Figure 1 intersects the strike of granite sills at the border in many places, as well as the strike of the schistose sediments. This map of the outlines of the granite area by Paige was taken from *U.S. Geol. Surv. Folio 219*. It is obviously generalized, and the contact is drawn as nearly as possible between areas dominantly granite with sedimentary inclusions and areas dominantly of sediment containing granite sills. The broad tongues of granite extending southwestward from the principal mass in T. 3 S., R. 5 E., and westward in the southeastern part of T. 2 S., R. 4 E., are examples of such generalized mapping. Much of the granite in these two areas is in the form of thick sills dipping away from the central area. The contacts, as shown, run at large angles to strike of schist and strike of sills.

In a belt of approximately 2 miles' width paralleling the granite contact on the northwest side of Harney Peak the schistose sediments are deformed into many nearly recumbent folds whose axial planes dip northwest and whose axes pitch at low angles to the southwest (Fig. 4). In many places throughout this area cleavage may be seen dipping at angles less than the dip of the beds (Fig. 5). The average of forty measured dips in this area was 15°. A number of small strike faults of low dip were observed in the same area (Fig. 6).

In a belt of equal width on the southeastern side of the Harney Peak dome in T. 3 S., Rs. 5 and 6 E., the schistosity and bedding dip more steeply, the average of thirty-five dips being about 35° to the southeast. While perhaps these facts may be explained in other ways, they are at least consistent with the following: Before the arrival of the granite the sediments had been folded into nearly recumbent folds by the advance of the overthrust sheet from the southeast. The axial planes dipped approximately 10° southeast. The lower short limbs of the drag folds were thinned and in places faulted out. On the upper limbs of the drag folds the cleavage was steeper than bedding. The rise of the Harney Peak granite tilted the beds to the northwest on the northwestern side until their dips were reversed and the cleavage was nearly horizontal. The tilting to the southeast steepened the dips of both beds and cleavage.

On the north side of the granite in T. 2 S., R. 4 E., the fold axes trend north and northeast, whereas on the south side of the same granite they trend northwestward. North of Custer the trend is northwestward, while east of Custer it is

[12] *Op. cit.*

FIG. 4.—Axial portion of a recumbent fold in metasiltstone. Four miles north of Harney Peak

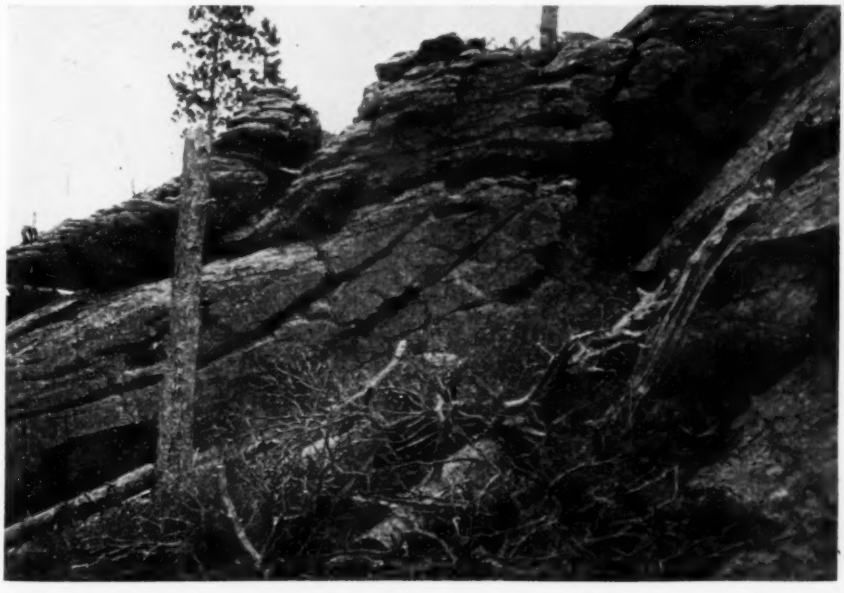

FIG. 5.—Cleavage cutting bedding in metasiltstone and dipping at a lesser angle than the dip of the beds. Two miles northwest of Harney Peak.

eastward. In both instances it would appear likely that the westward and southwestward projections of granite had deflected the fold axes not into parallelism with the granite, as has been so often stated, but outward from it.

Fold axes clearly are deflected from a straight course in the neighborhood of Bear Mountain, and the most logical conclusion is that this deflection was caused by the force of intrusion of the granite.

Considering the parallelism of folds northwest and southeast of Harney Peak with the major axis of the dome and the overthrust-fault trace, together with the lower dips of axial planes of folds and inclusions in parts of this area, it seems almost equally probable that the folds were oriented in part by the forces causing the overthrust.

Since much the greater part of the granite of the Harney Peak area lies northwest of the overthrust and between the two zones of cross faulting, it would appear that the main occurrence of granite may have been localized by the faults or the granite may have produced the faults slightly in advance of its arrival. Since, also, granite occurs in numerous small masses south and southeast of the Harney Peak mass but ceases almost entirely northwest of the Harney Peak mass and since the older granites are more abundant toward the southeast, it seems likely that the granite advanced from a southerly, perhaps southeasterly, direction.

FIG. 6.—Minor thrust fault in metasiltstone beds. Location same as Figure 5

The statement of Van Hise[13] that a secondary flow cleavage parallel to the granite contact and produced by the granite has obliterated an earlier cleavage is scarcely supported by the facts.

[13] *Op. cit.*

Flow cleavage has been folded and a secondary cleavage superimposed on an earlier one, but in all the cases that came to the writer's attention both cleavages were readily observable. It would fit the facts better to state that regional cleavage has been deflected near the granite to a direction more nearly parallel to that contact.

In view of all these data the following would seem to be a plausible hypothesis: The advance of the granite from the southeast caused overthrust faulting and deflection of fold axes and flattening of axial planes of folds at the front of the overthrust. The arrival of the granite was accompanied by the upfaulting, tilting, and doming of a restricted area between the zones of cross faults and in front of the overriding mass where the sediments were recumbently folded. The intrusion of the granite caused further deflection of fold axes and tilted the axial planes away from its center. The laccolith-like structure was localized by the nearly horizontal schistose sediments.

MODES OF OCCURRENCE OF THE GRANITE AND PEGMATITES

IN THE BEAR MOUNTAIN AREA

The intrusive relations of the upper contact of granite and schistose sediments at Bear Mountain (Fig. 3) are similar to those of a laccolith, but the relations in the deeper part of the granite are unknown. Isoclinally folded quartzite, metalimestone, amphibolites, and mica schists dip outward from a central granite core at angles of from 15° to 35° on all sides except for a portion on the west where relations are concealed by overlapping Paleozoic formations. Sills of granite penetrate the inner rim of sediments near the main granite contact. Superimposed on the outward-dipping limbs of the dome are minor folds which on the eastern, southeastern, and southern sides pitch southeastward at low angles.

In the few places where such observations were possible, it was noted that the short limbs of the minor folds were in such a position as to indicate that they had been produced by an overthrust toward the granite or an underthrust away from it. If, however, the minor folds are older than the granite, these data would have no significance relative to intrusion mechanics.

At several points some 3 miles to the northeast and southeast of the Bear Mountain granite isoclinally folded schist occurs, the axial planes and axes of which are nearly horizontal.

From these facts it is concluded that the Bear Mountain granite invaded an area of schistose sediments deformed into nearly recumbent folds. The fold axes trended northwest-southeast and pitched southeast at low angles. The effect of the intrusion was to produce the laccolith-like structure.

IN THE HARNEY PEAK AREA

As has been noted and commented on by a number of writers, schistose sediments cut by a few granitic intrusives in the areas bordering the Harney Peak granite mass pass gradually into granite containing inclusions of schist as the center of the area is approached. In the transition zone thick granite sills separated by thin screens of schist occur (Fig. 7). Where sills coalesced or were cut by dikes, the schists became inclusions. Many cases have been observed in which the bedding and schistosity of the inclusion were parallel to the same in the bordering rocks and to the sill surfaces while the direction of maximum elongation of the inclusion was not. Well-defined foliation in some masses of granite in the bor-

der zone dips steeply and intersects both schistosity and direction of elongation of schist inclusions at high angles.[14] These granite masses are dikes.

In the border zone of the granite in places—for example, in the central part of T. 3 S., R. 5 E.—many parallel, short, thick sills of granite are distributed along a line perpendicular to their strike, and their dips are away from the central area

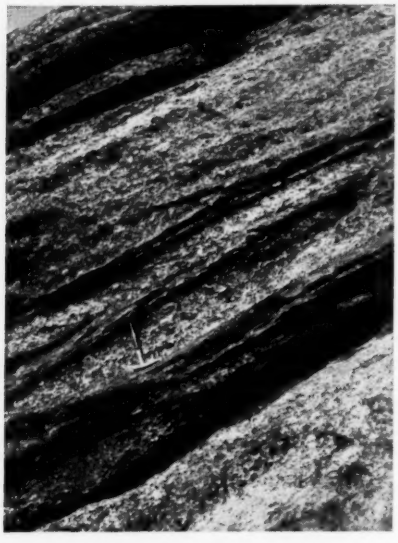

FIG. 7.—Thick sills of granite separated by thin screens of schists. From the schist-granite transition zone, southwest of T. 2 S., R. 5 E.

of granite. They resemble tongues of granite that have spread laterally along many planes between schistose layers from the top of a radial dike.

In the interior of the Harney Peak mass multiple sill structure is very conspicuous in places (Fig. 8). This structure is best seen from the air and apparently has not been noticed by all observers. This large-scale layering so prominent from a distance becomes much less so as one approaches it. It is not to be confused with a parallel structure on a smaller scale which somewhat resembles foliation and is to be found in the same rock (Fig. 9). The two structures, however, are undoubtedly related.

The multiple sill structure seen in the foreground in Figure 8 dips in the same general direction and at approximately the same angle as do the metalimestone and amphibolite inclusions near by. The foreground of the photograph is in the Needles area near the center of Section 28, Figure 2. Harney Peak is in the right background. Areas dominantly granite stand out in relief against the more heavily forested areas, where schist inclusions are much more numerous.

The mass of granite from which the Needles were eroded appears to be composed of several tongue-shaped sills elongated in the direction of dip (N. 30° W.) and less wide in the direction of strike, which is tangent to the Harney Peak dome surface. Relative to this structure, Balk says:

> . . . . and the schist cupola of the Black Hills exhibits immense flat dikes of granite and pegmatites, but although the general structural plan and form of these masses are reasonably clear, the cause of these extraordinary features is, as yet, hard to analyze.[15]

Paige states that

> the central mass presents a rude layering, visible only on a large scale and due in a broad way to the arrangement of the minerals of the rock. This layering dips outward with the dip of the schists and become flatter as it approaches the summit of the mass.[16]

But neither Balk nor Paige mentions the fact that there are two structures involved. The larger structure described above is, in the writer's opinion, quite

[14] Balk, *op. cit.*, Figs. 8 and 9.

[15] "Structural Behavior of Igneous Rocks," *Geol. Soc. Amer. Memoir 5* (1937), p. 40.

[16] *Op. cit.*

FIG. 8.—Aerial-photo of Harney Peak–Needles area from the south, showing multiple sills and cross joints. Forested areas are underlain by granite with many inclusions.

clearly due to multiple sill intrusions, while the smaller structure may be a flow structure, which will be discussed farther on.

Pegmatite dikes of varying sizes may be seen in many places, some cutting schists, some cutting fine-grained granite, and others cutting earlier pegmatites (Fig. 9, 10, and 11). All instances noted were of steeply dipping dikes cutting other dikes or more gently dipping sills. No sills were seen which at any point cut a dike.

The central granite of the Harney Peak area, then, is believed to be an assemblage of sills, tongues, and dikes of granite of different compositions, textures, and ages. The composite of all intrusions has produced a structural unit clearly constituting a dome as exhibited by the dip of granite sills, the distribution and orientation of inclusions, and the lines of force necessary to reorient the pre-existing structures into their present positions. The structure of the Harney

FIG. 9.—Pegmatite cutting foliated granite. Joints at left are same as prominent joints in Figure 8. From the Needles near center of Sec. 28, T. 2 S., R. 5 E.

FIG. 10.—Veins of pegmatite cutting vertically sheared granite resembling aplite. Exposure on Needles highway, west center of Sec. 28, T. 2 S., R. 5 E.

Peak dome appears to be similar in many ways to the stromatolith described by W. G. Foye[17] from the Haliburton-Bancroft area.

Projecting upward the outward-dipping contact of sills and sediments at the border of the granite on the northwest and southeast, it would appear that the now exposed central granite lies many thousand feet below the former upper granite contact in the dome center. How many feet of sediment lay above that surface is difficult to estimate. One can scarcely avoid the conclusion that the granite now exposed in the center of the Harney Peak dome crystallized at depths of several miles at least.

[17] "Are the Batholiths of the Haliburton-Bancroft Area, Ontario, Correctly Named?" *Jour. Geol.*, Vol. XXIV (1916), pp. 783–91.

The outward-dipping border sills have some resemblance to ring dikes, especially since some of them do crosscut the schists and are true dikes—for example, the Rushmore granite near Keystone. They differ from ring dikes in that their dips are much less than those of most ring dikes, and there is excellent evidence that the central mass has risen and not sunk. Conceivably, however, it may have been domed up and later have sunk.

MISCELLANEOUS OCCURRENCES

In the region of Custer the schists dip steeply and generally strike in continuous lines without abrupt changes of direction for considerable distances. The common form of granitic intrusion in the areas where this is true is the steeply dipping sill. In places, swarms of many parallel

FIG. 11.—Older, fine-grained granite cut by thin pegmatite seams and containing large replacement phenocrysts of microcline. From SE ¼ Sec. 27, T. 2 S., R. 5 E.

sills occur with only thin screens of schist between. Such an occurrence near Mayo, 6 miles south of Custer, has been described by D. J. Fisher.[18] Among other occurrences in the region is one about 1 mile northeast of Custer and a second about 2 miles southwest of the same town. Were these granites in crosscutting occurrences, the assemblage might be termed "dike swarms." They are like a giant lit-par-lit structure.

Many pegmatites in the Custer region appear in cross section in a form similar to very large boudinages. They are roughly elliptical in cross section and possess rather blunt ends. Whether these have been continuous masses and were pinched off by pressure or whether they are and were during intrusion discontinuous blister-like bodies and advanced as such, as suggested by Fisher,[19] is an interesting question.

As stated above (p. 437), the relations of intrusives within the area of quartzites southeast of Custer are largely discordant ones. Some are stocklike; others are true dikes.

It may be said in summary, then, that the form of the intrusive depends largely upon the structure of the invaded rock. Where folding is particularly complex, more intrusives have discordant relations; where strikes are fairly straight and dips fairly steep, sills are the common form; and where dips are low, a dome has formed with the separate intrusives favoring the sill relationship.

THE BLACK HILLS PRE-CAMBRIAN BATHOLITH

The geological map (Fig. 1) shows many areas where granite has protruded through the cover of schistose sediments from below. It would seem reasonable that these masses coalesce below into a larger batholith which advanced to its present position by piecemeal intrusion, just as the Harney Peak granite is believed to have done.

THE GRANITES AND PEGMATITES

INTERNAL STRUCTURES

As stated in the introduction, it is not the purpose of this paper to present detailed data on the internal structures of the Black Hills pre-Cambrian granites. The mapping of flow layers, joints, and faults is, as yet, very incomplete. There are, however, a few facts of considerable importance to which attention should be directed.

If the granite magma of the Harney Peak dome advanced as a large mass and the dome was enlarged by expansion outward, owing to additions of magma in the interior, the border zone should contain the oldest granite, the most pronounced foliation, and perhaps feather joints, marginal fissures, and upthrusts.[20] If, on the other hand, as is indeed the case, flow structures in general are very poorly developed in the marginal intrusions, the granite is there younger on the whole than in the central area; and if marginal fissures and upthrusts are rare or lacking, it would seem that the manner of intrusion was somewhat different from that of an expanding interior.

Foliation is well developed in much of the finer-grained older granites and in some pegmatites. An interesting case is in the granite from which the Needles have been eroded (Fig. 9). Here the foliation dips with the surfaces of the multiple sills and with the metalimestone inclusions toward the northwest. The foliation is due to the alternation of layers of coarse- and fine-grained granite.

[18] "Preliminary Report on Some Pegmatites of the Custer District," *S.D. State Geol. Surv., Rept. of Investigations No. 44* (1942), p. 4.

[19] *Ibid.*, p. 5, and personal communication.

[20] Balk, "Structural Behavior . . . . ," *op. cit.*, p. 101.

Whether this is a flow structure or has been caused by pegmatite intrusions into finer granite parallel to sill surfaces or by segregation of coarser and finer materials into alternate bands is not clear. In view of the well-defined multiple intrusions on a large scale and the difference in texture of the layers, the second hypothesis is favored.

As may be seen in Figure 9, still later pegmatite is intruded in nearly vertical dikes across the foliation. These later pegmatite intrusions are nearly parallel to the principal joints in the Needles granite, which are believed to be tension joints at right angles to the direction of expansion. If so, the joints are more consistent with expansion parallel to the strike of a local sill which is tangent to the Harney Peak dome than to expansion of the larger unit of structure—the dome itself. In other words, the dome is the result of the sum of a large number of local expansions taking place at different times rather than of a central expansion of the dome as a unit, and the cross joints are oriented accordingly.

On the whole, the pegmatites show very little postintrusive deformation, while the earlier granites are conspicuously sheared in places. Faults of small displacement accompanied by slickensides have been noted in a few places cutting pegmatites. One such occurrence is near the dam below Stockade Lake in Sec. 27, T. 3 S., R. 5 E.; and another in Sec. 28, T. 2 S., R. 5 E., in a road cut on the Needles Highway $\frac{1}{4}$ mile northwest of the switchback.

Plications in pegmatite and quartz veins are of rare occurrence. Such as do exist either have replaced some soluble folded layer in the schists or were folded while plastic, for thin sections reveal no brecciation, preferred orientations of minerals, or strain shadows. No structures identifiable as phacoliths have been observed.

PETROGRAHY

The petrographic features of the pre-Cambrian granites and pegmatites of the southern Black Hills have been the subject of many excellent papers, and only those features that have a bearing upon the mode of emplacement will be discussed here. For a description of the petrography the reader is referred to the papers of Van Hise,[21] F. L. Hess,[22] Victor Ziegler,[23] Darton and Paige,[24] G. M. Schwartz,[25] K. K. Landes,[26] J. P. Connolly and C. C. O'Harra,[27] Garvin L. Taylor,[28] Helen Stobbe,[29] E. L. Tullis,[30] and Fisher.[31]

The granitic facies is generally a medium-grained gray rock containing microcline, albite, quartz, biotite, muscovite, and accessory apatite, zircon, and some titanite and allanite. Where sheared, it commonly contains sillimanite. Tourmaline, so common in the coarser grained

[21] *Op. cit.*

[22] "Tin, Tungsten and Tantalum Deposits of South Dakota," *U.S. Geol. Surv. Bull. 380* (1908), pp. 131–63.

[23] "The Differentiation of a Granitic Magma as Shown by the Paragenesis of the Minerals of the Harney Peak Region," *Econ. Geol.*, Vol. IX (1914), pp. 264–67.

[24] *Op. cit.*

[25] "Geology of the Etta Spodumene Mine," *Econ. Geol.*, Vol. XX (1925), pp. 646–57; "The Tin Mountain Spodumene Mine," *ibid.*, Vol. XXV (1930), pp. 275–84.

[26] "Sequence of Mineralization in the Keystone Pegmatites," *Amer. Min.*, Vol. XIII (1928), pp. 519–30, 537–58.

[27] "The Mineral Wealth of the Black Hills," *S.D. School of Mines Bull. 16* (1929).

[28] "Pre-Cambrian Granites of the Black Hills," *Amer. Jour. Sci.*, Vol. XXIX (1935), pp. 278–92.

[29] "A Brief Description of the Pegmatites Southwest of Custer, South Dakota," *Econ. Geol.*, Vol. XXXII (1937), pp. 964–73.

[30] "Pegmatites of the Black Hills," *Black Hills Engineer*, Vol. XXV (1939), pp. 68–86.

[31] *Op. cit.*

varieties, is much less common than biotite.

In the more common types of pegmatite, which in the Black Hills is so abundant that it is generally called "granite," are albite, microcline, perthite, quartz, muscovite, and tourmaline. Apatite is common, but zircon and titanite appear less abundant than in the finer-grained granites. In these rocks as an occasional constituent in considerable quantities is garnet. In some places the garnet is a principal constituent of the rock. Euhedral dodecahedrons and trapezohedrons up to 1 inch in diameter occur.

In places the garnet is to be found near inclusions of schist and metalimestone, suggesting that it may be a product of assimilation; in others it occurs in banded granite, the structure of which might suggest a relict bedding. While no chemical analyses of the garnets are available, their optical properties are those of almandine and not of grossularite or andradite. The foliated structure may be a flow structure, so that, while they may owe their origin to contamination by foreign matter, it is by no means certain that this is the case.

Foliated garnetiferous pegmatite may be seen in highway cuts at the Needles and near the dam at Stockade Lake.

Another fact of importance to which insufficient attention has been given is the frequent occurrence of sheared granites in which sillimanite partly replaces mica and feldspar. Sillimanite and andalusite occur also in pegmatites where there is no evidence of shearing. In these latter places they are probably the results of contamination with aluminous sediment.

RELATIONSHIPS OF THE EARLY AND LATE INTRUSIVES

In a cut on the Needles Highway about 200 yards southeast of the upper marble quarry, granite may be seen that has been locally transformed into schist as a result of shearing. The schist contains rounded pebble-like masses of quartz, zoned garnets, and even unaltered granite itself imbedded in a foliated matrix of sillimanite, muscovite, and some biotite. The sheared aggregate is cut by numerous apophyses of unaltered graphic granite and pegmatite. Granite cut by vertical shear planes and intruded by later pegmatite may be seen in the highway cut at the Needles (Fig. 10). In the latter instance and in some others the sheared granite strongly resembles aplite. These facts show that an earlier granite was completely solidified before the intrusion of the pegmatite.

The older, finer-grained granite facies occurs in greater quantities near the center of the Harney Peak dome in Sections 34 and 35 (Fig. 2) and in the south center of T. 3 S., R. 6 E. (Fig. 1). On the western and southern slopes of the high ridges in Sections 34 and 35 below outcrops of normal-textured granite are talus piles of enormous blocks of that rock. Accumulations of talus below outcrops of the more coarsely crystalline pegmatites have not been observed to be made up of large blocks.

In the south center of Section 27, T. 2 S., R. 5 E., on the border of the dominantly fine-grained rocks to the southeast and the pegmatites toward the northwest is fine-grained granite cut by small veins of pegmatite and containing replacement phenocrysts of microcline (Fig. 11). A continuation of such a process would transform normal granite into pegmatite.

Both granite and pegmatite occur that are quite clearly products of replacement of schist (Fig. 12). Many of these reproduce the earlier-folded structures of the sediments. The total amount of pegma-

tite that is a replacement of older granite and of granite that is a replacement product of sediment is unknown, but only a small amount of rock of this origin has been definitely recognized.

On page 441 was noted the occurrence of granite and pegmatite, consisting of many parallel sills separated by thin screens of schist. In many of these there is considerable mineralogical difference between the adjacent sills. Some contain considerable quantities of tourmaline or muscovite; others, little of these minerals. The unavoidable conclusion is that the differentiation of magma into the various portions took place outside the present environment.

Other dikes and sills having no internal separations of schist but composed of layers differing in mineral content have also been observed. Some of these contain central zones rich in quartz. Many of these banded sills are believed to owe their structure to a continuous differentiation of magma at the source as intrusion progressed. The outer parts of the sill or dike usually represent the first intrusion; and, as crystallization proceeded there, the later fractions followed and occupied the central area.

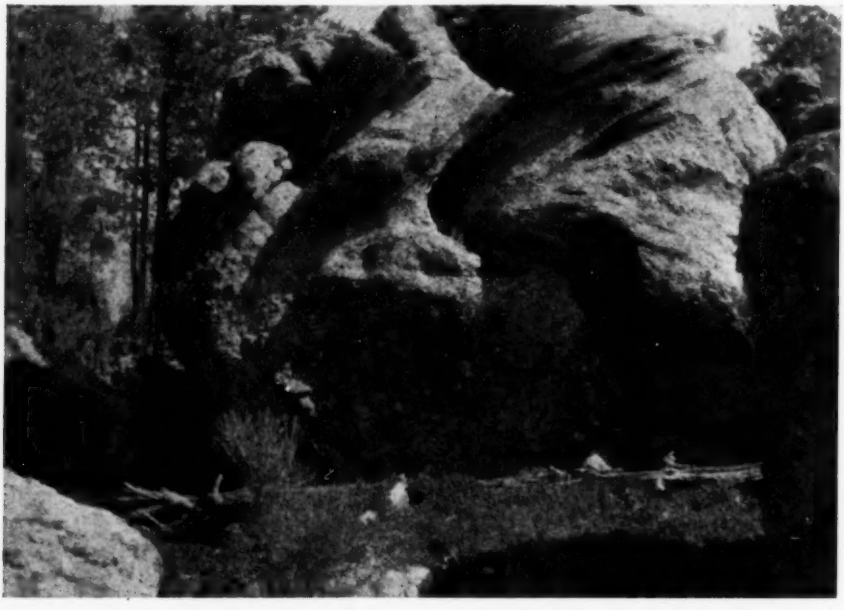

FIG. 12.—Folded schistose sediment partly replaced by granite. Two miles north of Harney Peak

INCLUSIONS IN THE HARNEY PEAK GRANITE

STRATIGRAPHY

In the Harney Peak granite the inclusions of mica-schist are the most numerous and widespread. Those composed of quartzite, metalimestone, and sedimentary amphibolite are confined to a somewhat limited area in the southeastern part of T. 2 S., R. 5 E., and the northeastern part of T. 3 S., R. 5 E. Of these

three the quartzite inclusions are, with few exceptions, nearer the axis of the Harney Peak dome than are those of metalimestone, while by far the greater number of amphibolite inclusions are found farther from this axis.

It is, however, by no means certain that this indicates the true stratigraphic order of the formations, for in nearly recumbent folds such as these have been found to be, there must be inversion. But whether inverted or not, the quartzite, metalimestone, and amphibolite beds dip outward from the Harney Peak dome and do not reappear again for considerable distances in any direction. If these formations are the same as the ones at Bear Mountain, then they have been brought upward in both domes and have not been stoped downward in either. As previously stated under "Regional Stratigraphy," the stratigraphic sequence of metasedimentary beds occurring as inclusions in the Harney Peak granite is very similar to the sequence of beds surrounding the Bear Mountain dome, namely, quartzite, metacalcareous rocks, sedimentary amphibolite, and finally mica-schist grading upward into quartzose beds containing calcareous concretions. The last-named beds are to be found only at the borders of the Harney Peak granite and doubtfully occur as inclusions. Whether the rocks of the two areas correlate is open to some question, for, while the order of lithological sequence is the same, the amphibolites at Bear Mountain are very much thicker than those at Harney Peak. However, they may have been faulted out in the latter area or thickened by folding or strike faulting at Bear Mountain. Another difference is the presence at Bear Mountain of the formation designated "amphibolitic quartzite" and its absence at Harney Peak. This formation may be a local replacement vein of quartz in the upper part of the calcareous sedimentary amphibolite formation. Such replacement veins are very common in amphibolites elsewhere in the Black Hills pre-Cambrian.

DISTRIBUTION AND ORIENTATION

Figure 1 shows the generalized dip and strike of the metalimestone inclusions and their approximate location with respect to the Harney Peak granite. Figure 2 shows the precise location of all the known inclusions of this rock and the dip and strike of bedding or axial planes of folds in every case where such data were determinable. The solid circles indicate the location of inclusions whose dip and strike could not be obtained. In all, eighty-five metalimestone inclusions were found and studied.

As may be noted in Figure 2, the metalimestone inclusions occupy the periphery of an area somewhat rhombic in shape. The longer axis of the rhomb trends approximately N. 35° E. and measures a little over $4\frac{1}{4}$ miles between outcrops of the metalimestone. The width, or minor axis, measured in the same way is about $3\frac{1}{4}$ miles.

In shape the inclusions are generally flat slabs parallel to bedding or axial planes of folds. In size they vary on the average from a thickness of a foot or two up to 40 feet, and in length from 10 feet to more than 100 feet. Two of the inclusions are large enough to be quarried for road material.

Most of the dips of the metalimestone inclusions are less than 35°; and of the forty-eight measured dips, forty-one have a major component in a direction away from the central axial region. Of the remaining seven, four are practically horizontal, two strike at right angles to the dome surface, while only one was found dipping toward the central axial

region. Thus, both in distribution and dip this series of inclusions combines to outline a well-defined xenolith dome.

These facts concerning the distribution and dip of the metalimestone inclusions, which are also representative of the quartzites and amphibolites, do not seem to bear out the idea of Paige[32] that the "stratigraphic sequence is destroyed" or that of Balk[33] that "adjacent xenoliths do show gentle dips but they strike at random." The evidence, on the other hand, would seem to indicate that a sequence is, on the whole, well preserved, and that the dips show a remarkable degree of consistency. When it is considered that the beds from which the inclusions were derived had been complexly folded before the intrusion of the granite (as indicated in part by the presence of isoclinal folds within some of the inclusions) and that each of these xenoliths has been completely surrounded by granite, the perfection of the dome is truly amazing. Had the apex of a major isoclinal fold in the metalimestone layer occurred on the flank of the present dome, the formation would not have been traceable around the structure, and the dome as outlined by the inclusions might have escaped detection.

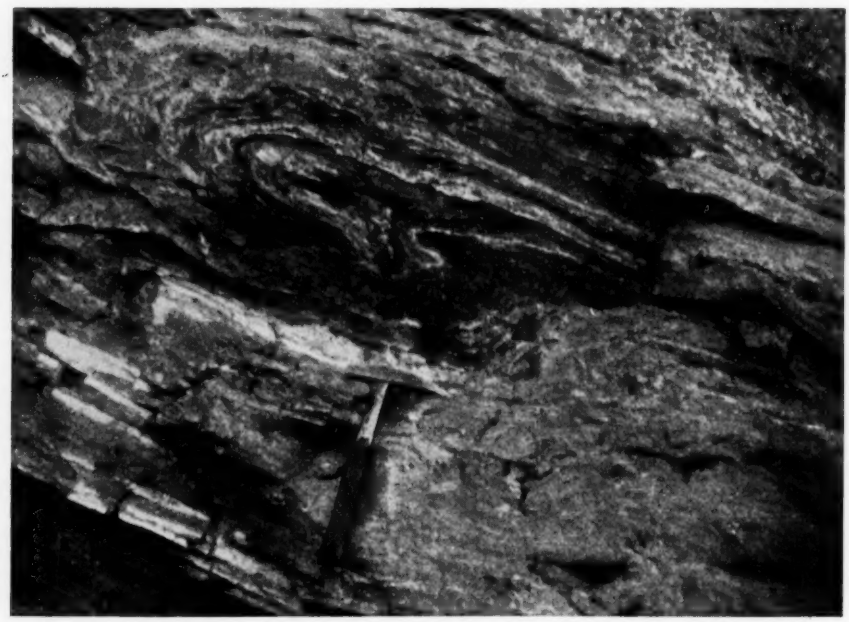

FIG. 13.—Folded metalimestone inclusion in granite. From SE ¼ Sec. 22, T 2 S., R. 5 E.

The consistency of the orientation and distribution of the metalimestone inclusions furnishes some excellent evidence as to the nature of the deformation of the region. When these inclusions from the tightly folded strata were spread apart by the granite, their strike was inevitably found to differ at various places, but this variance can in no way be considered as

[32] *Op. cit.*

[33] "Inclusions and Foliation . . . . ," *op. cit.*

"random." The present regularities of dip and strike seem certainly to yield considerable evidence not only concerning their pregranite positions but also concerning the nature of the displacement by the granite. The inclusions could have been moved upward, downward, or laterally in the bedding plane, or at any angle to it, without loss of their original relationships of dip and strike. Only if they had been rotated during their displacement would these relationships have been obliterated. The fact that most of the metalimestone inclusions have so clearly preserved the dome structure indicates that random rotation has been at a minimum or lacking. This is a very significant point with reference to the manner of the granite intrusion and the nature of the deformation.

FIG. 14.—Folded schist inclusion in granite. Dip of axial plane and pitch of axis are at rather low angles. From NW ¼ Sec. 3, T. 3 S., R. 5 E.

The lack of perfect alignment of the inclusions, especially in Sections 4, 10, 27, 28, and 34 (Fig. 2), may possibly be explained as the result of minor folding or faulting in the original beds, the existence of two or more metalimestone layers, or in part by differences in topographic elevations. But, far more likely, it is because the metalimestone formation has been raised higher or pushed farther outward at some points than at others as the result of greater amounts of intrusive granite at these places. In any case, the lack of perfect alignment, with the maintenance of fairly uniform peripheral strikes and outward dips, indicates that outward displacement, either lateral or upward, was a large factor in the mode of emplacement of the granite. Such displacement would readily result from the concentration within a limited elliptical area of a large number of intrusive sills

fed from smaller nearly vertical dikes, the sills spreading at the margins of the already solidified central masses. On the other hand, if partial replacement were the entire factor involved in spacing the inclusions, a more perfect alignment of them might be expected. The systematic orientation of inclusions has frequently been regarded as evidence that the xenoliths are roof pendants. That the metalimestone inclusions in the Harney Peak granite are not roof pendants seems clear for several reasons, namely:

1. The inclusions lie many thousands of feet below the original upper surface of the granite.
2. The inclusions are separated by many hundreds of feet of granite and are relatively small compared to the masses of granite.
3. Nearly all xenoliths are flat slabs with granite occurring in contact on the downdip side or edge, at both ends in the direction of strike, on the flat under surface, and on a part of the flat upper surface. Many others occur with granite in contact on the entire upper and lower surfaces and on the updip edge. None were seen with a vertical dimension of more than a few feet.

FIG. 15.—Nearly horizontal quartzite inclusion in granite. From near center of Sec. 27, T. 2 S., R. 5 E.

Unsupported inclusions of country rock in ore veins have been widely regarded by students of ore deposits as furnishing almost certain evidence of partial replacement. Of such inclusions Alan M. Bateman,[34] for example, writes:

> The frequent observations of small islands of country rock entirely enclosed within mineral bodies puzzled geologists for a long time, and it was not until replacement became understood that their presence could be explained. . . . . They are suspended residuals of country rock that escaped replacement while the surrounding rock was converted to ore. . . . Where they contain bedding or other structural features that are oriented with similar structures of the wall rock, they constitute the strongest evidence of replacement.

The analogy of the suspended residuals having structural features similar to

[34] *Economic Mineral Deposits* (New York: John Wiley & Sons, Inc., 1942), p. 106.

their wall rocks with the oriented inclusions in the Harney Peak granite is obvious. In the latter case, however, the systematic orientation of the xenoliths is not regarded as sufficient evidence that they have been isolated by partial replacement. This point will be discussed further in the following section on metamorphism.

PETROGRAPHY AND METAMORPHISM

The metalimestones.—Far more attention was paid to the metalimestones than to any other rocks occurring as inclusions in the Harney Peak granite and surrounding the Bear Mountain granite, since they offer greater possibilities for studying the effects of metamorphism, reaction, and assimilation. Approximately one hundred and fifty specimens were studied in thin sections in the laboratory.

The minerals occurring most abundantly in the inclusions of metalimestone are calcic plagioclase, diopside, tremolite-actinolite, phlogopite, muscovite, clinozoisite, scapolite, several chlorites, and quartz. In lesser amounts are to be found forsterite, hornblende, titanite, apatite, iron sulphides, albite, microcline, graphite, allanite, rutile, garnet, epidote, and tourmaline.

Calcic plagioclase, generally An_{80}, was probably the first metamorphic mineral to be formed. It apparently replaced the carbonates directly and, in turn, was replaced in part by less calcic plagioclase, microcline, quartz, pyroxene, amphiboles, micas, clinozoisite, and scapolite.

Some crystals of An_{80} are surrounded by two zones of progressively less calcic plagioclase (An_{60} and An_{40}), while other crystals are cut by veinlets of these two, the An_{40} in the center. These relations are believed to be due to reactions of alkalic-feldspar liquid from the granite magma with bytownite crystals rather than by consecutive growths.

Another type of zoning consists of as many as six alternations of high and lower calcic plagioclase. Crystals of microcline and microcline-perthite containing poikiloblastic inclusions of sericitized plagioclase and myrmekitic intergrowths of plagioclase and quartz occur at the contacts of pegmatite and inclusion. These contact portions are intermediate in composition between granite and metalimestone. They resemble granite and might be overlooked unless the rock were studied under the microscope.

Where scapolite has partially replaced An_{80}, a zone of less calcic plagioclase lies at the contact of the two in many instances. In some cases a zone of clinozoisite lies at the contact of calcite and plagioclase and in other cases at the contact of calcite and scapolite.

Next to calcic plagioclase, diopside is perhaps the most abundant metamorphic mineral of the metalimestones. The pyroxene crystallized later than the feldspar and with the latter forms a rock of the composition of iron-poor gabbro. In places the "gabbroic" rock is cut by veins of nearly pure calcic plagioclase (Fig. 16). This apparent inconsistency in age relations of plagioclase and pyroxene may possibly be explained if the plagioclase consists of two generations—one older and one younger than pyroxene—but it is more likely that a somewhat ferruginous dolomite was cut by nearly pure calcite veins. Later metamorphism accompanied by the introduction of silicon, aluminum, and a little sodium changed the dolomite to the gabbroic rock and the calcite veins to the anorthositic rock.

Some of the anorthositic veins contain considerable scapolite and clinozoisite as replacements of plagioclase. Plagioclase partially replaced by scapolite is in many

places accompanied by sericitized feldspar and apatite.

The amphiboles actinolite-tremolite are very common in the metalimestone inclusions and contact rocks, and hornblende is less common. The amphiboles were formed later than the plagioclase and some pyroxene, and contemporaneously with other of the latter mineral. Phlogopite accompanies actinolite in many places. Sulphides, titanite, and garnet appear to be more common in the portions of the rock containing hornblende.

Forsterite, partially altered to antigorite, sheridanite, and penninite, occurs in the metacarbonate rocks in which little or no plagioclase was observed. Tremolite and phlogopite accompany the forsterite but are not known to be contemporaneous with the olivine. Since many grains of forsterite show considerable alteration to chlorite, while diopside and actinolite do not, it is thought that the olivine was once more abundant than now, for pseudomorphic grains of chlorite are in considerable abundance in some places. Whether forsterite was formed earlier or later than plagioclase, diopside, and actinolite was not determined.

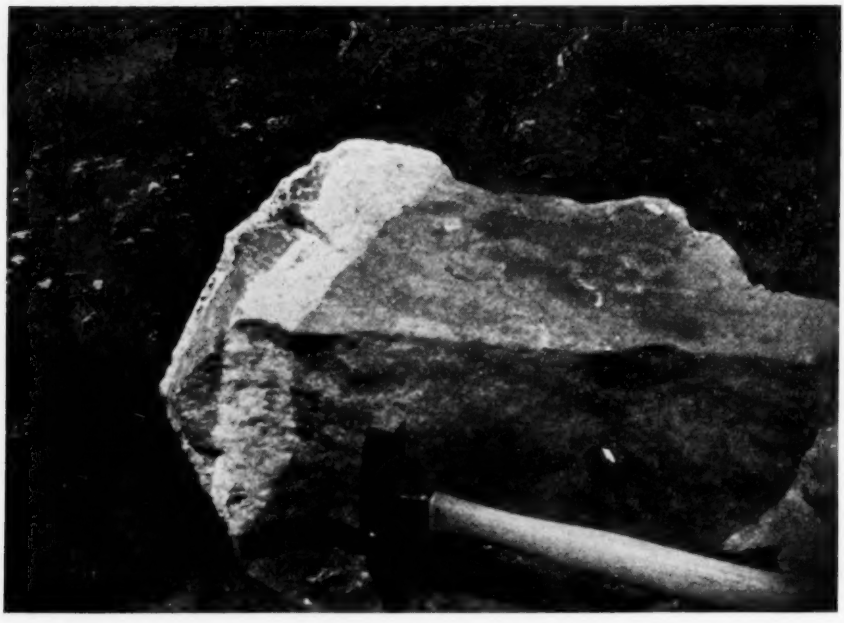

FIG. 16.—Vein of bytownite cutting diopside-plagioclase rock. The vein has the composition and texture of anorthosite, the larger mass has the properties of gabbro. Both are of metamorphic origin. From eastern part of Sec. 26, T. 2 S., R. 5 E.

Titanite, allanite, rutile, sulphides, especially pyrite, and graphite occur in small amounts in the contact rocks but rarely in the granite. Garnet is in greater abundance in the granite than in the metacalcareous inclusions, while apatite is abundant in both rocks.

The mineral changes may be summarized as follows:

Calcic plagioclase formed early. The necessary silica, alumina, and soda were derived either from the impure metacarbonate rock or from the granite.

With the depletion of alumina and possibly a fall in the temperature, forsterite and diopside crystallized or, where water was available, actinolite-tremolite and phlogopite developed.

Where more iron and alumina were present, the feldspar was less calcic, and hornblende and garnet formed in addition.

The formation of the quartz-plagioclase intergrowths and the replacement of the calcic by less calcic plagioclase, zoisite, and microcline are believed to be the effects of the later pegmatites.

The formation of rutile, titanite, sulphides, allanite, scapolite, apatite, sericite, and chlorite likewise accompanied or followed the introduction of the pegmatites and were dependent upon them for sources of Ce, Cl, H_2O, P_2O_5, S, and Ti.

The partial metamorphic effects of the earlier granites upon some carbonate rocks were the formation of rocks of gabbroic and anorthositic composition. Upon the inclusion of these and other metacarbonate rocks in the granitic and pegmatitic magmas, reactions took place which partially or wholly converted them into granite.

To determine the total extent of these changes by which carbonate rocks have been transformed into granite would require an enormous amount of very detailed field and laboratory work. And, while the evidence is lacking that large amounts of sediment were so changed, it is equally lacking that the reverse is true. The best evidence that partially digested carbonate rocks are not readily recognized in the field is that several competent observers have studied the area and failed to note them.

The formation of veins of bytownite by reaction of granite magma with calcite suggests the possibility that larger masses of anorthosite might under some conditions be formed in the same way. The further reaction of the bytownite crystals with magma to produce less calcic plagioclase suggests, likewise, a possible origin for some syenites and might help explain some associations of these two rocks. Conceivably some anorthosite and syenite may be intermediate products of the conversion of limestones to granite.

Whether we call this process "assimilation" or "replacement" is of little importance, so long as we call the products of the melting, or reaction, "granite" and the mass a "batholithic cupola or dome." The question remains as to the principal means by which the granites and pegmatites came to occupy space originally occupied by the sediments. The finding of these transitions between metacalcareous rock and microcline granite does not leave one with a feeling of great surety on this point. However, in spite of the lack of convincing evidence as to whether or not assimilation and replacement have been important factors in emplacement, there is excellent evidence, as pointed out above, that space has been made for the granite by uplift and lateral displacements.

The amphibolites and quartzites.—The amphibolite inclusions for the most part lie outside the line of outcrop of metalimestone inclusions. The position of the few which are found to lie within this line may be explained as due to derivation of these amphibolites from local impure facies of the metalimestones.

The amphibolites are generally schistose aggregates of quartz and intermediate to calcic plagioclase partly replaced by subeuhedral crystals of hornblende, actinolite, and garnet. Clinozoisite-epidote, micas, titanite, sulphides, and calcite are common but occur in small amounts. Some diopside and chlorites

were seen in a few places. Forsterite, rutile, scapolite, allanite, and tourmaline were not observed in these rocks.

There is little doubt of the sedimentary origin of the amphibolite inclusions. They occupy a stratigraphic position, vary in composition across planes that lie parallel to the bedding in the metalimestones, contain an abundance of calcite, and have the composition common to metamorphosed dolomites.

No detailed petrographic studies were made of the quartzites underlying the metalimestones or of the mica-sillimanite schists lying above the amphibolite. Some of the quartzites contain a little plagioclase, diopside, amphibole, garnet, and titanite. The mica-sillimanite schists are composed dominantly of biotite, muscovite, and quartz. Sillimanite is concentrated in small, flat, almond-shaped masses in which fine needles of sillimanite have partly replaced the mica and quartz.

METAMORPHISM OF THE BEAR MOUNTAIN CONTACT ROCKS

The petrography of the calcareous gneiss and marble surrounding the Bear Mountain granite is quite different from that of the calcareous inclusions in the Harney Peak granite. Calcic plagioclase, forsterite, diopside, and scapolite were not observed in the twenty-five specimens studied, and zoisite was much less abundant. On the other hand, microcline and albite were found in considerable quantities, and actinolite occurs in divergent crystal aggregates with lengths of as much as 10 inches. In the Bear Mountain contact rocks, muscovite and phlogopite occur abundantly, while titanite, apatite, tourmaline, and occasionally zircon and rutile are to be found. The presence of quartz and calcite is nearly universal. Some of the calcareous gneisses strongly resemble banded granite aplites in composition and texture. They show their original sedimentary nature by changes in composition across the bedding, which is parallel to the underlying quartzite, and by their mineral composition, which is characteristic of metalimestones. The amphibolites of the Bear Mountain area are in all essential respects similar to the amphibolite inclusions in the Harney Peak granite. Green hornblende actinolite and garnet have partially replaced an aggregate of granular quartz, calcite and plagioclase varying from andesine to bytownite in composition. Biotite clinozoisite-epidote, titanite, sulphides, and ilmenite are common. The amphibolites of the Bear Mountain area are almost certainly of sedimentary origin. They occupy a definite stratigraphic position and have internal structural features resembling bedding planes and a composition such as would be produced from metamorphism of impure dolomite.

SUMMARY OF CONCLUSIONS

1. The form of the igneous intrusions was determined largely by the structure of the invaded rock.

2. Granite is believed to have formed concordant injections between earlier granite sills as well as in the sediments.

3. Granite domes were localized at points where sediments lay in nearly horizontal position although complexly folded.

4. Domes are a composite of many outward-dipping sills and tongues and intersecting dikes.

5. The granite did not advance as a large mass but in successive smaller increments. Sufficient time probably elapsed between intrusions to allow complete crystallization.

6. The Harney Peak and Bear Mountain domes and the many other scattered

intrusives of the southern Black Hills probably coalesce below the schistose sedimentary cover into a major pre-Cambrian batholith.

7. Space for the granite was made by domical uplift, lateral spread, and replacement.

8. There was little or no downward stoping.

9. The advance of the granite was from the south or possibly from the southeast.

10. Overthrust faulting and recumbent folding preceded the arrival of the granite but were probably related to its advance.

11. The elongation of the Harney Peak dome is not parallel to the main tectonic lines in the Black Hills pre-Cambrian, while the major axis of the Bear Mountain dome is so oriented.

12. The Harney Peak dome grew by lateral accretions.

13. The Harney Peak dome is outlined by systematically oriented and distributed inclusions.

14. Many individual intrusives possess floors, but there is no evidence of one below the whole dome.

15. The granite and pegmatite now exposed in the interior of the Harney Peak dome crystallized at depths of several miles.

16. Flow structures and joint patterns in some individual masses of granite conform to the ideal pattern of the local mass.

17. Foliation has been produced by flow in the liquid state, replacement of bedding, multiple intrusion, and shearing of solid granite.

18. Many inclusions were isolated by coalescence of parallel sills and by intersecting dikes and sills and were never engulfed in liquid magma; hence were not oriented by flow of liquid magma.

19. Differentiation of the granites and pegmatites was largely pre-intrusion.

20. Because of the general lack of good flow structures and in spite of the short, thick forms with blunt terminations of many pegmatite bodies, the pegmatite magma is believed to have had low viscosity and a long crystallizing period.

21. There is little evidence that most pegmatites are replacements of granite or schist.

22. Rocks of gabbroic and anorthositic composition have resulted from the metamorphism of calcareous sediments.

23. The metamorphism of sediments preceded the reactions by which some were transformed into granite by replacement.

24. Zonal structure of plagioclase crystals was formed by successive reactions of bytownite crystals with granitic magma rather than by successive precipitations of less calcic plagioclase.

25. Syenite might be produced by the reactions stated in 24, if the process were carried on to the proper stage.

26. Rocks of aplitic texture and composition have been formed from sheared granite.

27. Porphyritic granite has resulted from the partial replacement of granite by large crystals of microcline.

ACKNOWLEDGMENTS.—For many valuable facts in this report the author is greatly indebted to several graduate students of the State University of Iowa: to Stewart H. Folk for much of the mapping of the Bear Mountain dome and of the metalimestone inclusions in the Harney Peak dome and for a petrographic report on nearly one hundred and fifty rock samples from these two areas; to Dr. Leonard Thomas for much of the stratigraphic and structural information in the area east and southeast of Custer; and to Dr. Robert Hamilton for similar data on the area in the Keystone region.

MARINE TOPOGRAPHY OF THE CAPE MAY FORMATION

PAUL MACCLINTOCK
Princeton University

ABSTRACT

The Cape May formation of New Jersey is a late Pleistocene accumulation of sand and gravel deposited when sea-level stood a score or more feet above that of today. The seaward part of the formation, containing fossils at several places, is marine, whereas valley deposits to the landward, contemporaneous in age, are fluvial. The formation was first considered to be Wisconsin in age, because it contains erratic stones. But more recently it has been considered as nonglacial, because it was deposited during a high stand of the sea and because it contains warm-water fossils: that is, as either interglacial or early postglacial during a temperature maximum. The present study approaches the question of age by an analysis of the topography of the marine portion of the Cape May formation. It is found to be that of low bars and shallow longitudinal depressions parallel to the present shore, drained and slightly modified by consequent fluvial erosion. From the evidence of the amount of erosion of the constructional topography of the marine part of the formation and the amount of weathering which has taken place, it may be rather confidently referred to an interglacial or interstadial interval, prior to the last episode of glaciation. And, furthermore, sea-level has not been higher than its present stand since this interglacial time.

INTRODUCTION

PREVIOUS WORK

Prior to 1890 references to coastal terraces in New Jersey are too general to be of significance, though the fact of submergence was widely accepted. In 1890 C. W. Coman[1] stated: "Although isolated terraces have been noted at different levels along the portion of the coast studied no continuous shore line, or series of terraces . . . . has yet been traced." He rejected evidence of a sea cliff north of the Manasquan River, because there is not "a line of beach sand and gravel and shells at that height." In 1896 R. D. Salisbury,[2] in reporting on the northeastern part of New Jersey, stated that "at various points there seems to be decisive evidence of submergency up to a level of 40 feet or so within recent (last glacial or later) time." In 1897 Salisbury[3] distinguished and named the Cape May formation. "The disposition of this formation seems to indicate that when it was deposited the coastal plain [of New Jersey] was depressed something like 35 to 45 or 50 feet below its present level, the amount varying slightly in different localities." As to age he has this to say: "The strict contemporaneity of this formation with the drift of the last glacial epoch is not established, but it is probably at least partly contemporaneous as inferred from their topographic relations, especially in the lower part of the Delaware valley."

Salisbury and G. N. Knapp[4] in their detailed account of the formation consider it to be partly marine or estuarine and partly of subaerial origin and contemporaneous with Wisconsin glaciation. Ernst Antevs[5] in 1928 points out that sea-level was lower during a glacial stage and that the fossils of the Cape May formation show a climate at least as warm as that of today, and so he considers

[1] *Ann. Rept. State Geologist of New Jersey, 1890*, pp. 130-31.

[2] *Ann. Rept. State Geologist of New Jersey, 1896*, p. 15.

[3] *Ann. Rept. State Geologist of New Jersey, 1897*, p. 19.

[4] "The Quaternary Formations of Southern New Jersey," *Geol. Surv. N.J.*, Vol. VIII (1917).

[5] "The Last Glaciation, with Especial Reference to the Ice Retreat in Northeastern North America," *Amer. Geog. Soc. Res. Ser. 17* (1928), pp. 83–93.

the formation to be of interglacial age, probably the last. H. G. Richards[6] in a comprehensive study of the fauna of the Cape May formation confirms earlier views of climate warmer than that of today. The fauna is comparable to the Eem fauna of southern Denmark, also referred to the last interglacial stage.

Paul MacClintock and H. G. Richards[7] consider the gravels in the Lower Delaware Valley to consist of nearly horizontal terrace deposits of interglacial age transected by the Wisconsin Valley-train sloping more steeply and descending to sea-level at Penns Grove in Salem County.

Since the dating of the Cape May formation has rested on the two phenomena of (1) a high sea-level and (2) warm-water fossils, there are the possibilities that it might date from the Sangamon, the Peorian, or a postglacial warm period[8] of higher sea-level than now. R. F. Flint[9] has summarized to date the opinions concerning the Pleistocene features of the Atlantic Coast. He identifies and describes in some detail the Surry scarp at 100± feet above present sea-level and the Suffolk scarp at 20–30 feet above sea-level. His work, however, deals chiefly with the region south of New Jersey. The surface configuration of the Cape May formation has received little or no attention. It is believed that detailed analysis of this topography yields an independent line of evidence as to the age of the formation.

[6] "Marine Fossils from New Jersey Indicating a Mild Interglacial Stage," *Proc. Amer. Phil. Soc.*, Vol LXXII (1933), pp. 181–214.

[7] "Correlation of Late Pleistocene Marine and Glacial Deposits of New Jersey and New York," *Bull. Geol. Soc. Amer.*, Vol. XLVII (1936), p. 307.

[8] R. Sandegren, "Ragundatraktens postglaciala utvecklings-historia enligt den subfossilia florans vittnesbörd," *Sveriges Geol. Undersökning* ("Ser. Ca," No. 12 [2d ed.; Stockholm, 1924]).

[9] "Pleistocene Features of the Atlantic Coastal Plain," *Amer. Jour. Sci.*, Vol. CCXXXVIII (1940), pp. 757–87.

MARINE CAPE MAY FORMATION

SECTIONS

The coastal part of the Cape May formation may be divided for convenience into two sections: (1) the sea-cliff section within which it forms a narrow terrace against an ancient sea cliff and (2) the bar section within which the formation is largely a bar behind which little or no cliffing of the mainland took place.

SEA-CLIFF SECTION

From Jersey Highlands to Brielle the Cape May formation abuts against a 30–50-foot scarp, cut in older sediments. The scarp was already extensively eroded before Cape May time so that the latter extends landward up the major valleys such as the Navesink, Shrewsbury, Shark, and Manesquan (see Fig. 1). But the seaward-facing pre–Cape May interfluves have been truncated as though by marine cutting during Cape May time. These latter scarps, produced during Cape May time, have themselves been dissected and softened by post–Cape May fluvial erosion. Since the scarps are composed of unconsolidated coastal-plain sediments (Cohansey and Kirkwood overlain by Pensauken and Bridgeton), this erosion was doubtless rapid, though in the unconsolidated sandy material the gullies, instead of being deep and V-shaped, are broad and roundheaded. The smaller of these gullies debouch with alluvial fans on the Cape May flat at the base of the scarp. The courses of these small scarp-dissecting streams after they reach the Cape May flat run parallel to the present shore line until they join larger transverse streams.

Drainage is so poor near the base of scarp west and northwest of Spring Lake

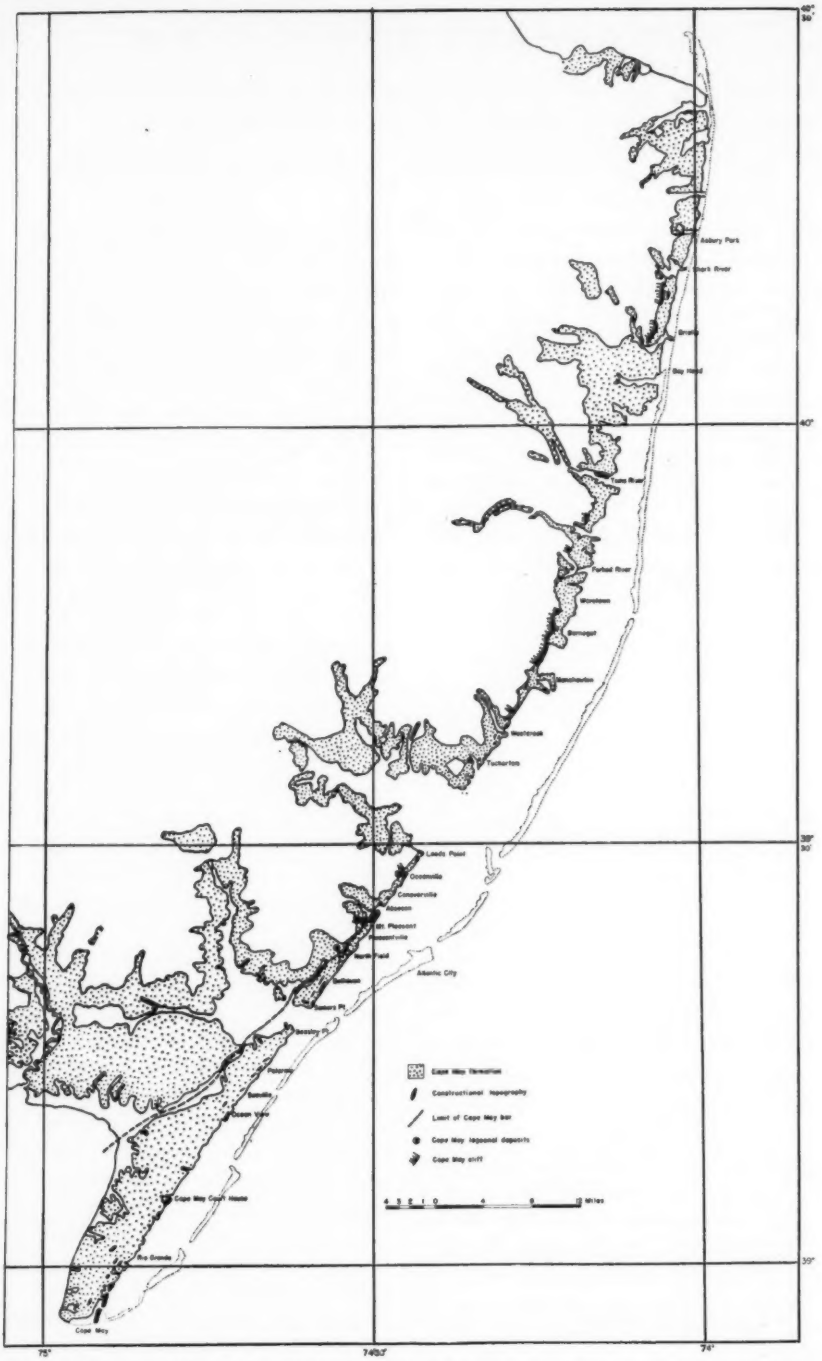

FIG. 1.—The coast of New Jersey. The base and the distribution of the Cape May formation are from the State Geological Survey map by Lewis and Kümmel, 1912.

that ditching and tile drainage has been necessary. There is a northeast-southwest "grain" of the topography on the Cape May formation parallel to the present shoreline showing that it is marine constructional rather than fluvial in origin. The amount of fluvial erosion suffered by the front of the escarpment shows that this feature is older than post-Wisconsin.

From Manasquan River at Brielle southward to Tuckerton occasional pre–Cape May interfluves exhibit subdued seaward-facing scarps rising above the Cape May level (Fig.1). None of these, however, is sufficiently well developed to be convincing as a sea cliff. It is only when they are considered in relation to the better developed features farther north that they contribute to the present study.

BAR SECTION

The topography of the Cape May formation along the coast, between the main valleys, shows a dominance of northeast-southwest ridges and depressions. Since the ridges are made of gravel, they are not of wind-blown origin. With very few exceptions the depressions are drained, that is, have surface outlets. In most cases there is no definite watercourse down the axis of the depression, though in one or two a little channel 2–3 feet wide and a foot or so deep has been cut. The predominance of the northeast-southwest orientation of the topographic features, parallel to the present shore, shows that they were made by wave and current action and that the fluvial erosion pattern is consequent and follows the "grain" of this original topography.

CAPE MAY PENINSULA

The surface of the peninsula, 32–33 feet above sea-level in the northern part and 25 feet in the southern, is very gently rolling. Considerable stretches are exceedingly flat with not more than 1 or 2 feet of relief in a mile. There are some patches of eolian sand, but in only a few places does it form dunes. There are such dunes along the west shore, a mile south of South Dennis, constricting the outlet of Tember and Beaver Swamp, and at Ocean View. Otherwise the topography seems to be that of sea bottom which has been modified by fluvial agents to the extent of integrating pre-existing depressions and draining the undrained places. It is therefore concluded that the Cape May peninsula is a marine bar or spit of Cape May age.

The presence of a constructional depression behind it, now the Great Cedar Swamp, suggests that it might have been an offshore bar. If so, it may well have been built up to and above sea-level of the time. The scarcity of Pleistocene dunes on its surface indicates that, if this were the case, the sea must have overtopped it in the latter part of the Cape May episode and largely destroyed the normal complement of dunes which are characteristic features of offshore bars. The evidence, discussed later, near Northfield and near Absecon of lagoon deposits covered by cross-bedded sands and gravels, all of Cape May age, confirms this deduction of a rising sea-level.

To test further the hypothesis that the Cape May bar was formed during a time of rising sea-level, a study was made of the subsea-level topography on the seaward slope of this bar. The study was to find out whether or not the gullies, dissecting the eastern slope of the bar, extended out under the peat of the coastal swamp which lies behind the present offshore bar. Soundings were made with a 15-foot rod which was pushed down through the peat until it crunched on the pebbly sand of the underlying mate-

rial. Plane-table, alidade, and stadia rod were used for accurate locations. It was found necessary to space the soundings in many places not more than 5–10 feet apart and to place them in rows in order to determine the slope of the bottom. been destroyed. It is therefore obvious that the present offshore bar was in existence and was protecting this seaward flank of the Cape May bar while sea-level rose at least its last 15 feet. There was a slight amount of wave and current

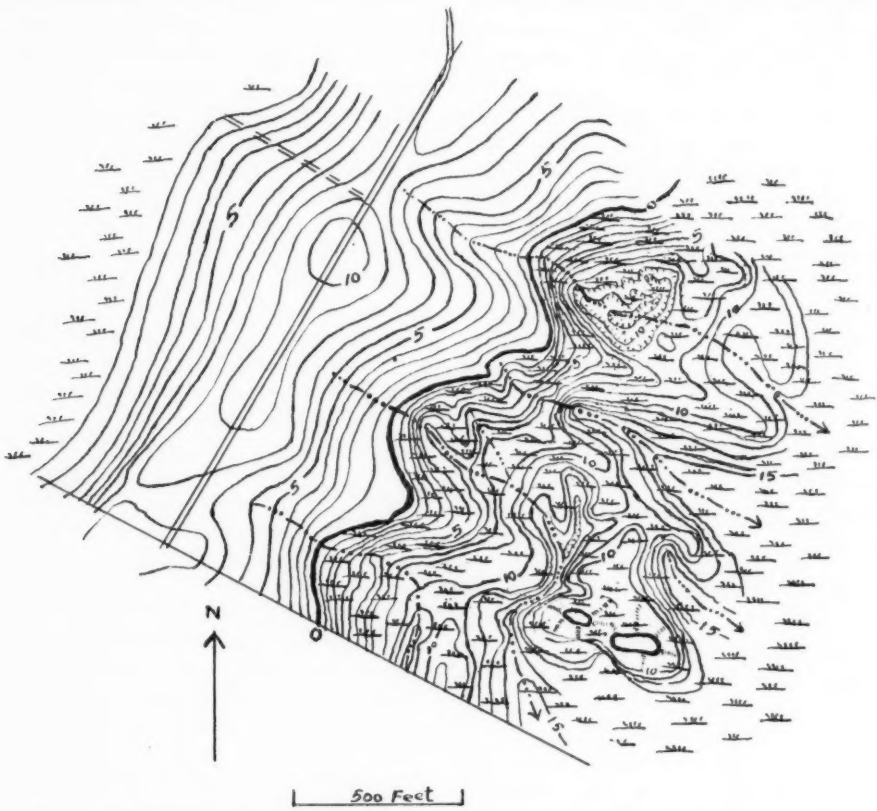

FIG. 2.—Detailed contour map of the inner edge of the coastal swamp 1½ miles northeast of Cape May. Contour interval is 1 foot; lines among the symbols for swamp show depth below sea-level.

Spot soundings were found to be inadequate because they allowed more than one topographic interpretation. The resulting map (Fig. 2) shows that the gullies above present sea-level do continue out under the peat. If ocean waves had ever washed against this as a shore, these subsea-level gullies would have action, as seen in the northern of the gullies on the map, but in general the peat accumulated in quiet water. From this study it is therefore inferred that the present offshore bar was formed as sea-level rose to its present stand. It seems a legitimate inference that the Cape May bar had a similar history.

Cape May City.—The western part of the city is built on a northeast-southwest ridge of Cape May gravel 10–15 feet above sea-level. This ridge is evidently a small bar on the seaward flank of the large bar. It is continuous for a distance of 3 miles, with a break at Schellingers Landing for Cape Island Creek and another for Mill Creek. The seaward side of the middle portion is eroded by fluvial action to a series of broad shallow gullies typical in sandy unconsolidated material. As seen in a gravel pit ½ mile south of Bennett, the Cape May gravel is iron-stained and weathered to a depth of 6 feet, below which it is white to gray in color. This depth of weathering as well as the amount of fluvial erosion shows the material to be older than postglacial.

Cape May Court House.—Here another small bar a mile long rises 15-18 feet above sea-level. A large sand and gravel pit shows relatively horizontal bedding, suggesting water more than a few feet deep. The drainageway on the landward side of the bar has evidently been enlarged by running water. But so large a depression paralleling the coast seems best interpreted as a constructional depression which has been enlarged and drained by stream work rather than a completely stream-cut valley.

Ocean View.—A low gravel ridge, ½ mile long, parallels the shore ¼ mile east of the highway. Again behind the ridge is an elongate depression interpreted as constructional in origin. The 42-foot hill just west of Ocean View is a large sand dune.

Palermo.—Just east of Palermo a low gravel ridge parallels the shoreline. The railroad cut through it discloses medium-sized gravel and sand of the Cape May formation.

Marmora.—A large gravel pit ¼ mile northwest of Marmora exposes 20 feet of Cape May gravel. It is fine pebbly sand at the top and has coarser gravel layers at the bottom, with pebbles up to an inch in diameter. The bedding is marine rather than fluvial. The surface of the formation here is 32–33 feet above sea-level.

HINTERLAND NORTHWEST OF CAPE MAY PENINSULA

The area presents gentle fluvial topography on the Cape May formation. The only exceptions comprise two low discontinuous ridges of gravel, one east–west through Dennisville, the other northeast–southwest ½ mile southeast of Mount Pleasant, and half-a-dozen low scarps 5–10 feet high notching interfluves at various levels up to 40 feet altitude. Sea-level was not stationary for long, or this part of the coast was protected from North Atlantic waves by the presence of a bar, just as the modern coastline has been.

SOMERS POINT TO ABSECON RIVER

A bar extends from Somers Point to Absecon River (Fig. 3). It is free at both ends but lies against the hinterland at Pleasantville. From Somers Point to Northfield the surface topography of the bar consists of long northeast-southwest ridges and depressions parallel to the axis of the main bar. The longitudinal depressions are all drained by relatively shorter and deeper transverse valleys. The depression, followed between Linwood and Seaview by the electric railroad (Fig. 4), can be explained only as a constructional feature modified by fluvial erosion. Also Figure 5, showing profiles across the bar, illustrates the constructional nature of the topography. In the western part of the village of Somers Point is an area of Pleistocene sand dunes and in Pleasantville is a single dune. Otherwise the bar is made of gravelly sand, typical of the Cape May formation, rising to 35

feet above sea-level. The details of the topography of the outward slope of the bar are seen to advantage in the grounds of the three golf clubs—at Somers Point, at Linwood, and at Northfield. The analysis of these details reveals constructional features modified by the erosion of running water. There are no undrained depressions left, but there are abundant places which evidently were undrained before fluvial erosion captured them. Also on each of the three golf courses there are gravel ridges parallel to the coast without streamways to landward commensurate in size and shape to streams that could have isolated the barlike feature by the agency of fluvial erosion. (Borings with a soil auger show that the material is sand and gravel rather than dune sand.) At the northern end of the bar, near Absecon River, two gentle longitudinal depressions score the crest of the bar. The point of land extending north on the east side of Ab-

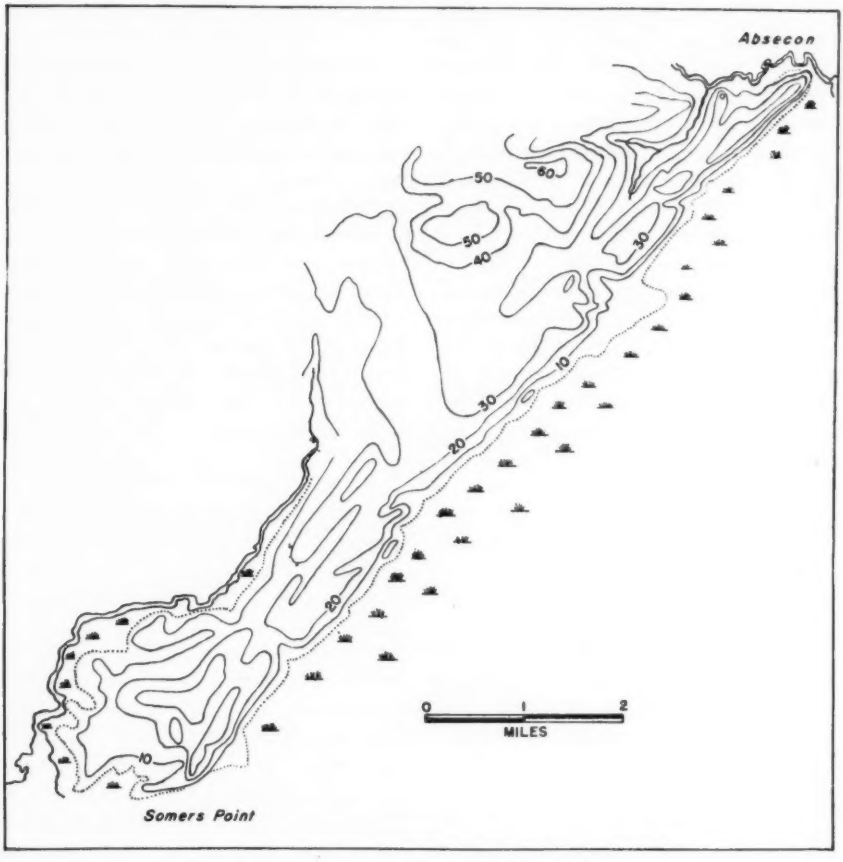

FIG. 3.—Cape May bar from Somers Point to Absecon

secon River contains a gravel pit exposing 15 feet of fine sand and gravel oxidized 12 feet deep below which it is white. Marine cross-bedding in the material predominantly dips southward, showing that a south-moving current participated in its construction and that, therefore, Absecon River has breached what was a continuous bar. The topography of the point is fluvial, but the main drainage lines on its surface have a northeast-southwest trend parallel to the ridge itself. It is therefore inferred that barlike constructional land forms have established the drainage pattern.

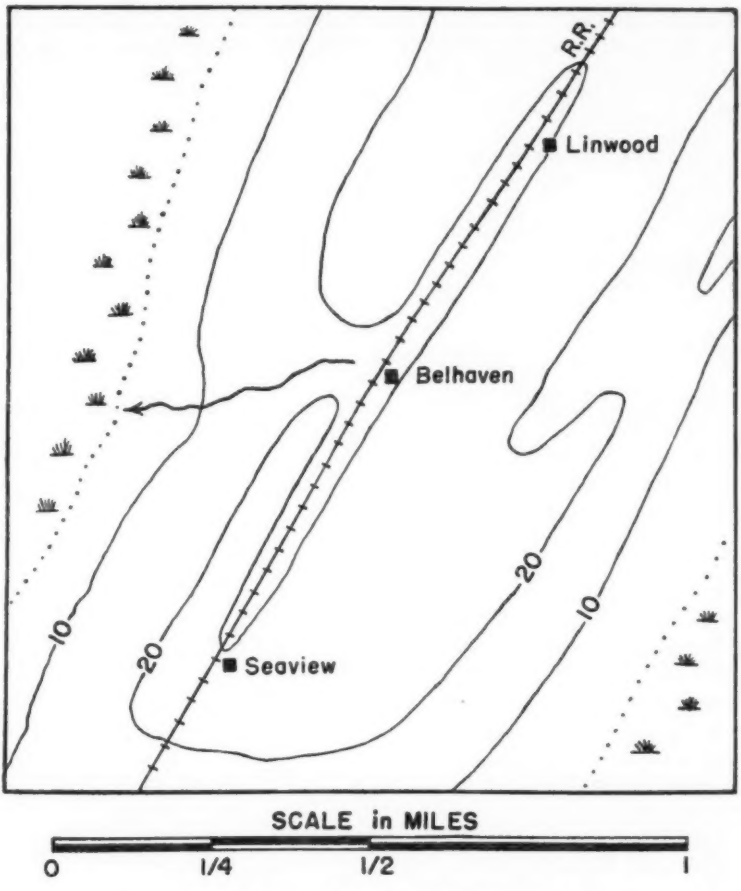

FIG. 4.—Detail of the top of the Cape May bar near Belhaven

LAGOON DEPOSITS

Behind the Cape May bar three exposures of lagoonal deposits were found (Fig. 1). At the Somers clay pit, 1 mile northwest of Northfield, silty clay 5–6 feet thick is covered, with a gradational contact, by 5 or 6 feet of sand and

gravel. The pit is not now working, but M. E. Johnson, state geologist, reports that the clay lies on pebbly sand.

A mile north of Mount Pleasant the Atlantic City Water Department is building a new filtration plant. Test borings show the material listed in Table 1. The ground surface here is 8 feet above sea-level. At the time of the visit with M. E. Johnson and S. K. Fox to collect material for study, excavation for the building had progressed through the clay and into the peat. Logs and pieces of trees are most abundant at the top and

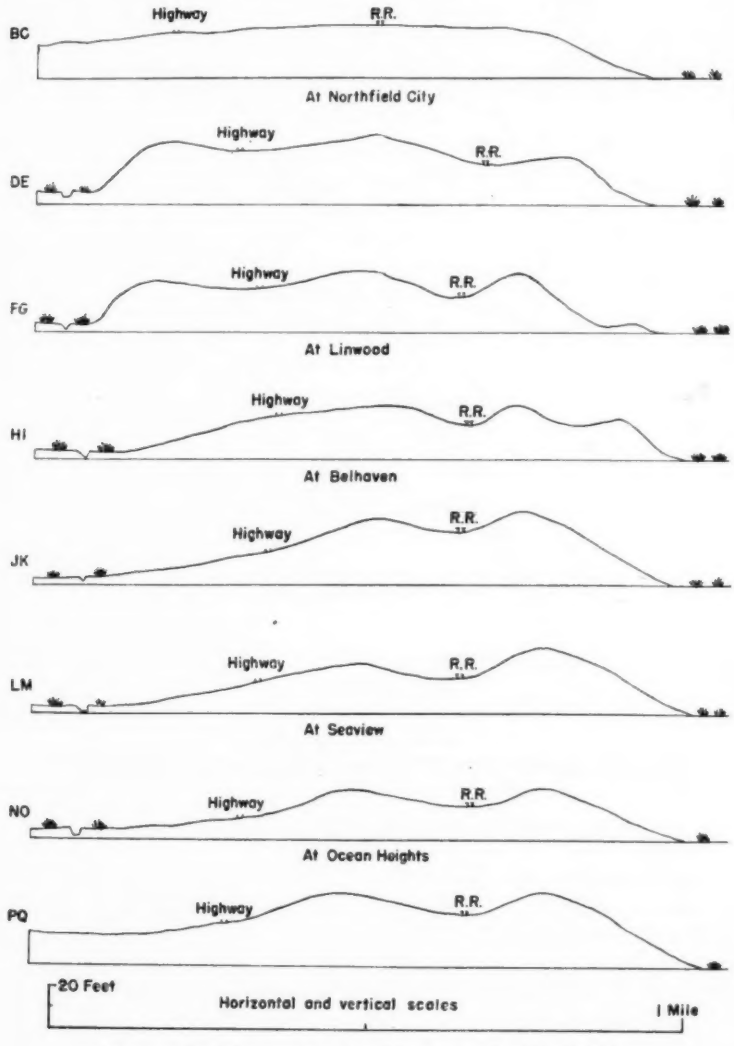

FIG. 5.—Profiles across the Cape May bar south of Northfield

bottom of the organic deposit with compact peat between. There are many ramifying channels, through the peat, filled with soft sticky mud. They seem to have been channels of small streams through the peat bog. Diatoms and pollen are present but no Foraminifera. Samples of the peat were submitted to Professor Paul B. Sears for pollen analysis with the following results:

TABLE 1

MOUNT PLEASANT WELL RECORD

Formation	Material	Feet
Cape May	Gravel and sand	15
	Fine brown sand	2
	Black clay	7
	Peat and "cedar swamp"	4
Early Pleistocene	Coarse sand and pebbles to 1 inch	9
Cohansey	Fine gray running sand and clay	3
	Fine brown sand (bottom of test)	8

Sample 2 feet above bottom of peat: pine 57 per cent, oak 22 per cent, hickory 9 per cent, linden 2 per cent, beech 3 per cent, sw. gum 2 per cent, birch-alder 2 per cent, walnut tr., chenopod-amaranth tr., etc. 3 per cent.

Sample at base of peat on gray sand: pine 49 per cent, oak 21 per cent, hickory 11 per cent, linden 6 per cent, beech 3 per cent, sw. gum 2 per cent, birch-alder 2 per cent, walnut tr., grass 1 per cent, composites tr., chenopod-amaranth tr., etc. 5 per cent.

His comment is: "These are distinctly temperate spectra. There are a few consistent differences suggesting slight cooling and/or increase in humidity from base to top, but not enough to make much of unless supported by a consistent drift in intermediate samples."

Samples collected by Mr. E. H. Ludwig from the test borings through the peat were studied for diatoms by Ruth Patrick, of the Academy of Natural Sciences of Philadelphia. Table 2 presents these findings.

Miss Patrick's conclusions are as follows:

> The diatoms would indicate that the water which existed during the time of the Swamp Cedar Vegetation was fresh with a high mineral content. Specimens of typically salt-water species are occasionally found which are probably contaminations of higher and lower levels. For the lower parts of the Swamp Cedar Vegetation—Bore 5—T–18 seems to indicate a more brackish condition. Likewise the upper parts of the Swamp Cedar Vegetation—Bore 5—T–13 seem to indicate brackish to marine conditions.
>
> The diatoms do not furnish any evidence that the deposit is very old. All of the forms may be found living today. Thus the deposit is probably of Pleistocene or more recent origin.

A mile northwest of Mount Pleasant a working gravel pit displays 12 feet of typical yellow Cape May gravel on 5 feet of pure white sand on a 2-inch layer of black muck on 3 feet of drab gray organic-stained pebbly sand. Scattered through the Cape May gravel in the pit are seams and thin layers of organic material. It appears that this is the shoreward margin of a swamp in which organic material was preserved.

The evidence presented by the lagoonal deposits is that of rising sea-level. There seems to have been a bar in Cape May time behind which the fresh-water lagoonal deposits accumulated. Further rise of the sea drowned the swamp and lagoon and spread cross-bedded sand and gravel over the site.

ABSECON TO LEEDS POINT

The higher parts of the village of Absecon rest on Cohansey and Bridgeton gravels, but in the eastern part a roundish constructional hill of Cape May gravel rises to 37 feet above sea-level.

The Conoverville basin is an inden-

tation in the Cohansey formation cut by streams in pre–Cape May time but floored at present with Cape May gravel. The hills of Cohansey material rise steeply from the relatively flat floor of Cape May material. The ridges of Cape May material that constrict its eastern edge have constructional topography and

TABLE 2

DIATOMS FROM BORES MADE AT ABSECON, NEW JERSEY

Bore	Depth (Feet)	Stratum	Diatoms
Bore 3			
T-8	16.21	Swamp cedar vegetation	No flora
T-9	17.21	Swamp cedar vegetation	Pinnularia maior Kütz. Pinnularia viridis (Nitzsch) Ehr. Diploneis ovalis (Hilse) Cl. Rhopalodia gibberula v. producta (Grun) O. Müll. Nitzschia denticula Grun. Nitzschia granulata Grun. Navicula pusilla W. Sm. Navicula vulpina Kütz. Paralia sulcata f. radiata Grun.
T-10	18.21	Boundary between swamp cedar vegetation and coarse sand and shell corn	No flora
Bore 4			
T-11	17.88	Swamp cedar vegetation	No flora
T-12	18.88	Swamp cedar vegetation	No flora
Bore 5			
T-13	16.23	Boundary between black clay and swamp cedar vegetation	Actinocyclus subtilis (Greg.) Ralfs Amphora ovalis (Breb.) Kütz. Chartoceras spore? Coscinodiscus Diploneis Smithii (Breb.) Cl. Opephora pacifica (Grun.) Petit Navicula digito-radiata v. Cyprinus (W.Sm.) V. H. Nitzschia panduriformis Greg. Paralia sulcata (Ehr.) Cl.
T-14	17.23	Swamp cedar	No diatoms
T-15	18.25	Swamp cedar	Caloneis formosa (Greg.) Cl. Diploneis voalis (Hilse) Cl. Navicula peregrina (Ehr.) Kütz. N. marina Jan. and Rabh. Nitzschia granulata Grun. N. sigma v. rigidula Grun.
T-16	19.23	Swamp	Achnanthes brevipes Ag. Diploneis ovalis (Hilse) Cl. quite a few specimens Nitzschia granulata Grun. Paralia sulcata (Ehr.) Cl.
T-17	20.23	Swamp cedar	Achnanthes brevipes Ag. Amphiphora sp. Diploneis interrupta (Kütz.) Cl. Diploneis ovalis (Hilse) Cl. quite frequent Nitzschia granulata Grun. quite frequent Paralia sulcata f. radiosa Grun.

TABLE 2—*Continued*

Bore	Depth (Feet)	Stratum	Diatoms
Bore 5—*Cont.* T-18.....	21.23	Boundary between swamp cedar vegetation and coarse sand and gravel	Achnanthes brevipes Ag. Caloneis Schumanniana v. trinodis (W.Sm.) Cl. Diploneis ovalis (Hilse) Cl. Opephora pacifica (Grun.) Petit Navicula peregrina (Ehr.) Kütz. N. pusilla W. Sm. Nitzschia plana W. Sm. Rhopalodia gibberula v. producta (Grun.) O. Müll.

seem to be bars built part way across the open side of the basin during Cape May time (Fig. 6).

The course of the Seaview Golf Club, 1 mile north of Conoverville, slopes gently and regularly to the southeast except in the southern corner where an oval hill of gravel 100 by 200 yards in extent rises 10 feet above the surroundings on all sides. The lower country behind the hill is wide and gentle without integrated drainage. The hill seems to be constructional rather than to have been isolated by post–Cape May erosion.

East of Oceanville the topography is not conclusive, but a flattish area of Cape May gravel has two barlike prongs, one to the northeast and the other to the southwest. These might have been fluvially isolated but are not incompatible with origin as bars or spits parallel to the shore.

Between Oceanville and Leeds Point, Cape May gravel lies against Cohansey. Paulin profiles of four roads between the main highway and the coastal swamp portray small longitudinal ridges and valleys (Fig. 7), and the characteristic orientation of the drainageways is dominantly northeast-southwest. There are no undrained depressions, and it might all be interpreted as fluvial topography. But the important point is that, if so, the maximum development of drainage has been parallel to the shore rather than headward away from it. The streams might conceivably have acquired this pattern if lateral tributaries working in the softer Cape May formation outgrew the main stream, which latter headed in more resistant Cohansey. Painstaking search, on the topographic maps, elsewhere in the state, where Cape May gravel lies against older formations, revealed no equivalent topography. It therefore seems best to account for the drainage pattern as having had original northeast-southwest topographic controls which must have been constructional in origin.

TUCKERTON TO TOMS RIVER

Tuckerton is built on Cape May gravel that shows gentle constructional topography in the form of low ridges and roundish hills without commensurate drainageways behind them. Between Tuckerton and Westcreek, a distance of 3 miles, seven longitunal ridges parallel the coastline. A mile north of Westcreek several patches of constructional topography are seen on both sides of the highway. A northeast-southwest gravel ridge 5–10 feet high lies west of the highway ½ mile southwest of Manahawkin. A gravel pit in the western part of Manahawkin shows delta bedding in the Cape May gravel. Paulin elevation of the top

of the foreset bedding is 37.5 feet above sea-level. While the top of the foresets does not necessarily prove sea-level of Cape May time, because scouring by the stream making the deposit might have cut below the sea-level, it at least does show that sea-level of the time was no lower than this figure.

A mile north of Forked River a low gravel ridge parallels the highway (northeast-southwest) and lies $\frac{1}{4}$ mile east thereof. Whereas the longitudinal depression behind the ridge might conceivably have been cut by running water, its width and orientation are more easily interpreted as constructional.

ANTIQUITY OF THE TOPOGRAPHY

It is thought that comparison of the amount of erosion which the Cape May topography has suffered with that of the late Wisconsin glacial land forms might give an estimate of the antiquity of the Cape May. Undrained depressions and poorly organized insequent drainage patterns are typical characteristics of late Wisconsin topography. Post-late-Wisconsin fluvial action has softened the

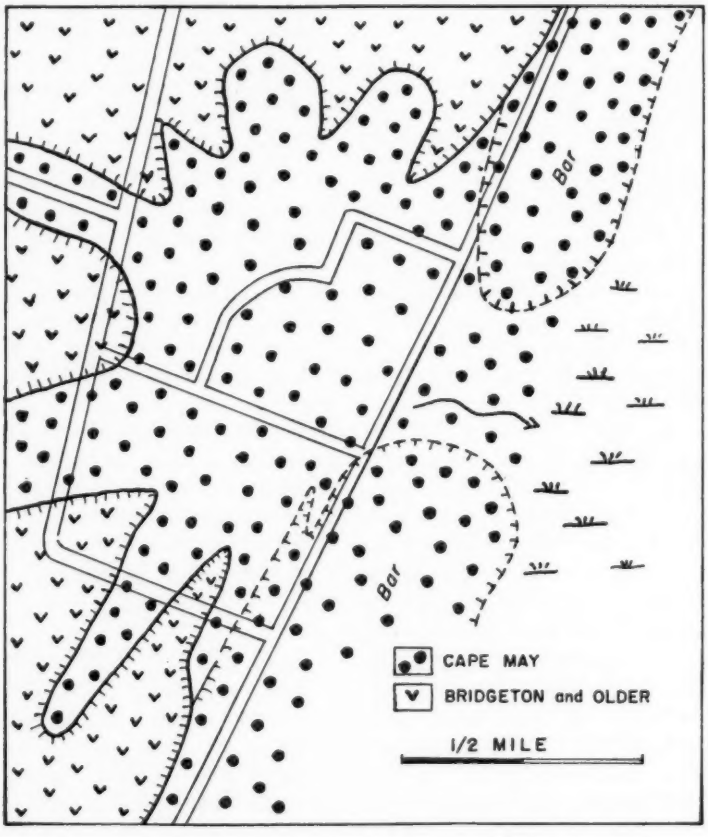

FIG. 6.—Diagram of the Conoverville Basin showing the Cape May bar

slopes, has partly filled with wash many of the depressions, has cut some gullies, and has breached and drained some depressions. But on the whole, fluvial erosion has made relatively little headway in destroying the original constructional

the topography were slightly older, most if not all the undrained depressions, typical of wave and current topography, would have been drained by surface streams and the drainage, while still following the main courses established

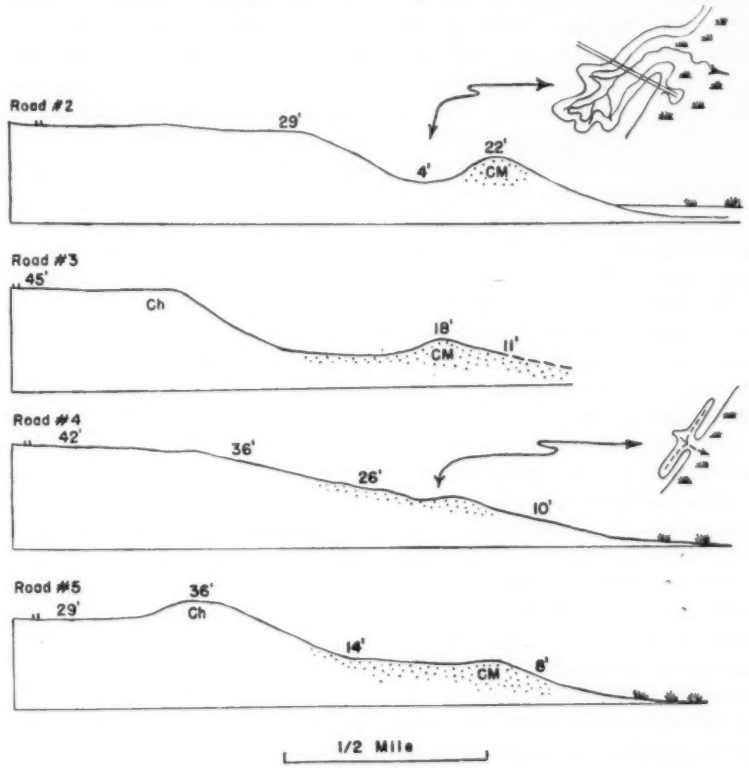

FIG. 7.—Northwest-southeast profiles across the seaward slope of the Cape May shoreline, drawn at intervals of about ½ mile, southward from Leeds Point.

land forms of both till and gravel deposits as they were left by the glacier. Constructional forms of marine origin dating from the same age, and within the same climatic province, would presumably have been modified to the same extent by fluvial agents. There would still be present undrained depressions and insequent drainageways wandering among constructional hills. If, however, among constructional features, would be integrated. It would be a fluvial drainage system set in a pattern of constructional topography. This condition is seen on the Illinoian drift hills in the Kaskaskia River Basin in central Illinois.[10] It would likewise be commensurate in drainage

[10] Frank Leverett, "The Illinoian Glacial Lobe," *U.S. Geol. Surv. Mono. 38* (1899), p. 71; P. MacClintock, "Physiographic Division of the Area Cov-

texture with the characteristic texture of the topography made by the agent of construction; in the present case, waves and littoral currents. Furthermore, the orientation of the pattern should be inherited from the orientation of the constructional features—in this present case, parallel to the shoreline. With greater age and further erosion, the constructional forms and pattern would all have been destroyed as on Kansan drift of Iowa and Nebraska, and only subsequent topography, dependent on the character of the material, would be left. In New Jersey the topography of the larger valleys, such as those of Toms River, Mullica River, and Great Egg Harbor River are of this latter type. They are consequent rivers on the coastal plain and have developed dendritic patterns, but they are pre–Cape May in age.

If the foregoing analysis be valid, it becomes evident that the topography of the Cape May formation along the coast is older than late Wisconsin and younger than Yarmouth. It is then either Sangamon or Peorian, for they were the times when sea-level was high. Opinion at present differs somewhat as to the magnitude of deglaciation and climatic amelioration of the Peorian stage. It is known from the small amount of weathering of the drift sheets that this stage was not comparable in length with the Sangamon, Yarmouth, or Aftonian. But it is not known to what extent the ice sheets disappeared or how warm the climate became. The Cape May was a time when the seas were warmer and sea-level was higher than today. Both suggest a climate warmer than that of today in this latitude and, therefore, deglaciation greater than at present.

R. J. Russell[11] finds, in the history of the Mississippi River delta, five episodes of erosion during the Pleistocene. These he attributes to five episodes of low sea-level, where the river entrenched itself, and correlates them, respectively, with the Nebraskan, Kansan, Illinoian, Iowan, and Wisconsin glaciations. There were four episodes of aggradation corresponding to times of high sea-level correlated with the Aftonian, Yarmouth, Sangamon, and Peorian. But, since there has been a great deal of sinking of the delta during its history, it is unsafe to use these data to designate the precise stand of the sea during any one of these episodes in relation to its present level. Russell's succession and correlations have been seriously questioned by J. B. Lucke,[12] who considers that the well data upon which Russell largely bases his deductions are far from conclusive. Until further evidence is forthcoming the extent of Peorian deglaciation and rise of sea-level remains questionable.

From the evidence in New Jersey the Cape May seems best referred to the Sangamon interglacial stage. It follows that Peorian sea-level was no higher, if as high, as the present stand. Since the Suffolk scarp, to the south, bounds the landward side of the Palmico formation, which is correlated with the Cape May, this scarp probably is also Sangamon in age, and the higher Surry scarp is older.

ACKNOWLEDGMENTS.—Field work was financed by a grant from the Department of Geology, Princeton University. W. C. Boyce was the field assistant. Mr. L. M. Jones and S. E. Hoy, of the Atlantic City Water Department, were most helpful.

ered by the Illinoian Driftsheet in Southern Illinois," *Ill. State Geol. Surv. Rept. Investigations No. 19* (1929), p. 23.

[11] "Quaternary History of Louisiana," *Bull. Geol. Soc. Amer.*, Vol. LI (1940), pp. 1199–1234.

[12] "Discussion 'Subsurface Pleistocene of Louisiana' by J. W. Fink," *Amer. Jour. Sci.*, Vol. CCXXXIX (1941), pp. 845–49.

ENVIRONMENTAL SIGNIFICANCE OF A SMALL DEPOSIT IN THE TEXAS PERMIAN[1]

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ABSTRACT

The Permian redbeds of north-central Texas have long been recognized as the sediments of a shoreline of aggradation, but little progress has thus far been made in explaining the specific circumstances of origin of distinctive individual deposits. The study which follows is an attempt to achieve this aim in the case of a single small deposit which represents a type of special interest to the paleontologist, since it contains a diversified assemblage of mixed terrestrial and marine fossils. This deposit is interpreted as a partly re-worked channel-fill laid down by a temporary fluviatile distributary discharging across extended tidal flats into a shallow coastal lagoon.

INTRODUCTION

LOCATION

The deposit described in this study—hereinafter referred to as "the fossiliferous deposit"—is exposed along a fork of Mitchell Creek in the northeast portion of Baylor County, Texas (see Fig. 1). It may be reached on foot from a point on U.S. Highway 283 three miles north of the intersection at Mabelle. About one-half mile east of the highway the upland surface terminates abruptly in a ragged escarpment overlooking the creek valley. One fork of the creek here flows through a steep-sided draw between the escarpment and an outlying mesa. This draw will be referred to as "Mabelle Draw," and the locality as the "Mabelle Draw locality."

LOCAL STRATIGRAPHIC RELATIONSHIPS

The shape and disposition of the fossiliferous deposit in the horizontal plane are largely concealed by overlying sediments; but in cross section, as exposed along the stream course, it appears as a thin lens of gray-to-yellowish clay, silt, sand, and gravel—irregularly laminated, poorly sorted, unconsolidated, and, for the most part, without visible bedding. It has a maximum exposed thickness of about 10 or 12 feet and is approximately 1,000 feet wide in the north-south direction.

The fossiliferous deposit is overlain, and bordered, by a sheet of gray or reddish-gray sediment consisting of well-sorted layers of silt and sand commonly arranged in an imbricate structure. Many of the sandy layers are more or less indurated and stand out as ledges in the exposures. This deposit will henceforth be designated the "imbricated deposit." It extends at least 300 feet beyond the fossiliferous deposit to both the north and the south and has a maximum observed thickness of about 5 feet.

The fossiliferous deposit and the imbricated deposit together form an extensive seam of relatively coarse and drab-colored sediment, which is sandwiched in between thick strata of fine reddish and purplish mudstone. Mudstone deposits crop out over a vast area in north-central Texas and attain a combined thickness of many hundreds of feet. For the purposes of this study "the

[1] Submitted, in more expanded form, in September, 1942, to the faculty of the Division of Physical Sciences at the University of Chicago in partial fulfilment of the requirements for the degree of Doctor of Philosophy.

mudstone" may be considered as a sort of undifferentiated "background" deposit of indefinite horizontal and vertical extent.

There are two limestone layers which enter into the picture at Mabelle Draw. The lower layer generally forms the rim of the draw, and the upper one, a terrace a short distance back from the rim. The two layers are each about 1–1½ feet thick and are separated by 6 or 7 feet of mudstone. The lower layer is about 40 feet above the top of the imbricated deposit.

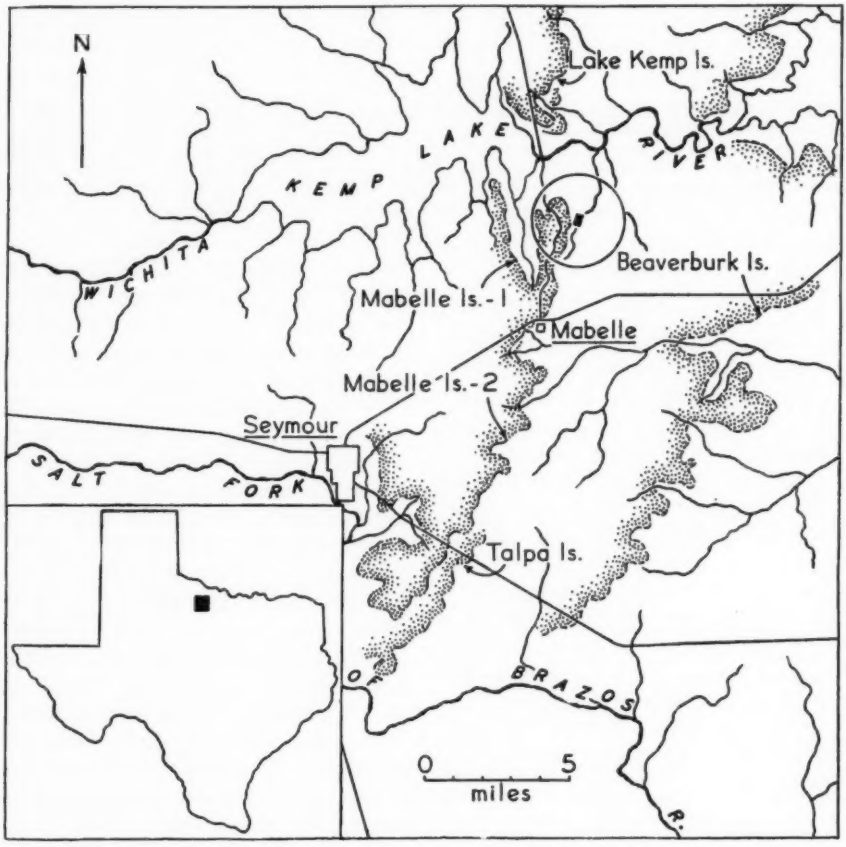

FIG. 1.—Index map of Baylor County, showing location of Mabelle Draw. The area covered by the geologic map (Fig. 2) is indicated by the black rectangle in the circle. Inset shows location of Baylor County in Texas.

AGE RELATIONSHIPS

The geologic age of the fossiliferous deposit may be determined from its stratigraphic position in reference to the two limestone layers.

One of these layers is shown by M. M. Garrett, A. M. Lloyd, and G. E. Laskey[2]

[2] "Geologic Map of Baylor County, Texas" (Austin: University of Texas, Bureau of Economic Geology, 1930). Scale: 1/48, 000.

on their "Geologic Map of Baylor County." They show only one layer in the vicinity of Mabelle Draw and identify this as the first, or uppermost, division of the "Maybelle" limestone.

The name "Maybelle" was originally given by A. S. Romer in 1928 to "a scarp-forming limestone . . . . which crosses central Baylor County from the Big Wichita River near the Kemp Lake dam to the Salt Fork about ten miles below Seymour."[3]

In the first edition of their Baylor County map, which appeared in 1930, Garrett, Lloyd, and Laskey plotted the outcrops of a number of layers of limestone between the Kemp Lake dam and the Salt Fork. Five they grouped together as divisions of the "Maybelle" limestone; and a sixth, about 40 feet above the Maybelle series, they named the "Lake Kemp limestone." In their columnar section they showed all of these limestone layers as members of a formation which they called the "Lueders formation."[4]

E. H. Sellards, in 1932, when he undertook to divide the entire lower Permian of north-central Texas into separate formations, followed Garrett, Lloyd, and Laskey in selecting the top of the Lake Kemp limestone as the upper limit of his Lueders formation, and the top of the Talpa limestone, 30 feet below the Maybelle series, as its base.[5]

Under the terms of this definition, the only question in regard to the age of the fossiliferous deposit at Mabelle Draw is whether it is located stratigraphically above the Talpa and belongs to the Lueders formation or whether it is below the Talpa and belongs to the underlying formation, which is the Clyde. Unfortunately, the Talpa limestone does not extend as far north as Mabelle Draw (see Fig. 1); so there is no horizon-marker in this locality to separate the bottom of the Lueders formation from the top of the Clyde. The position of the fossiliferous deposit with reference to the boundary between these two formations can be determined only by comparison of the stratigraphic interval between the limestone layers and the fossiliferous deposit at Mabelle Draw with the stratigraphic interval between the uppermost member of the Maybelle limestone and the established base of the Lueders formation farther south. The fossiliferous deposit is 50 feet below the upper limestone at Mabelle Draw. The base of the Lueders formation farther south, according to Garrett, Lloyd, and Laskey, is fully 75 feet below the uppermost member of the Maybelle. Assuming no marked lateral variations in thickness, the fossiliferous deposit would therefore be about 25 feet above the base of the Lueders and should be assigned to that formation.

It is possible, of course, that the limestone mapped by Garrett, Lloyd, and Laskey in the vicinity of Mabelle Draw as the uppermost member of the Maybelle may have been the lower, rather than the upper, of the two limestones there present. If so, the inferred interval between the fossiliferous deposit and the uppermost member of the "Maybelle" would be shorter, by 7 feet, and its distance above the base of the Lueders formation correspondingly greater.

Sellard's classification of the Lower Permian, including the Lueders formation, has not been accepted without

[3] "Vertebrate Faunal Horizons in the Texas Permo-Carboniferous Red Beds," *Univ. Tex. Bull. 2801* (1928), p. 74.

[4] Garrett, Lloyd, and Laskey, *op. cit.*

[5] E. H. Sellards, W. S. Adkins, and F. B. Plummer, "The Geology of Texas," *Univ. Tex. Bull. 3232* (1932), p. 169.

criticism. Romer,[6] in 1935, advocated on faunal grounds that the Lueders formation and the Clyde be transferred from the Wichita group to the Clear Fork. M. G. Cheney,[7] in 1940, advocated that all the formations in Sellards' Wichita group be raised to the rank of groups and that the limestone members in these formations be raised to the rank of formations. The writer's adherence, in this study, to the original classification proposed by Sellards implies no judgment upon the suggestions of Romer and Cheney; it is simply a matter of acquiescence in the most widely accepted usage.

The writer would like to suggest one minor change in Sellards' classification: namely, the emending of the spelling of the name "Maybelle" to "Mabelle." As previously stated, the "Maybelle" limestone was so named by Romer in 1928. Romer gave no type locality, stating merely that the limestone was "known locally" by that name. The local usage, however, obviously derives from the name of a post office 8 miles east of Seymour, which is spelled "Mabelle" not only on the post office itself but also in the official lists of the Office of the Postmaster General.

DESCRIPTIONS OF ASSOCIATED DEPOSITS

MUDSTONE

The mudstone which surrounds the fossiliferous deposit at Mabelle Draw is typical of the thick series of argillaceous sediments which are comprised within the Wichita and Clear Fork groups of north-central Texas. Although the continuity of this series is interrupted at intervals by limestone layers, which stratigraphers have utilized as horizon-markers, the great mass of sediment between these layers has remained, for the most part, "undifferentiated."

The 50-foot section of mudstone exposed at Mabelle Draw exhibits little significant sedimentological variation in either the horizontal or the vertical direction. It is undoubtedly true, however, that a more intensive study, conducted over a wider area, would reveal the presence of distinct depositional units.

The mudstone does not look much like stone at the surface. It weathers to a soft, porous clay, which everywhere forms a foot-thick coating over the bedrock. The latter would seem to be subject to disintegration at a very rapid rate, for a piece of it, placed in water, almost immediately crumbles into mud; but in its natural environment it seems to receive considerable protection from the surface clay, which becomes very sticky and nearly impervious when wet.

Owing to the coating of weathered material, it is impossible to observe the color of the fresh mudstone except in very recent natural or artificial excavations. The writer therefore sank test-pits at various points to ascertain whether there was any significant difference in the color of the weathered material as compared with that of the bedrock. The only observed difference was that the weathered material, being more porous, characteristically exhibited a somewhat lighter color-tone.

The actual color of the mudstone may therefore be safely inferred from the color of the surface material. The dominant hue, as indicated by the designation "redbeds," is a rich reddish brown; but the red shades off into vague horizontal bands of lavender, sienna, and gray. The banding seems to be due, for the most

[6] "Early History of Texas Redbeds Vertebrates," *Bull Geol. Soc. Amer.*, Vol. XLVI (1935), pp. 1597–1627.

[7] "Geology of North-Central Texas," *Bull. Amer. Assoc. Pet. Geol.*, Vol. XXIV (1940), pp. 65–118.

part, to variations in the relative abundance of iron and manganese oxides. The color effect is generally the result of a more or less uniform staining by combinations of these oxides, but it may also be concentrated in concretionary crusts and pellets.

One striking exception to the usual color pattern may be noted: Where the mudstone lies in contact with the under side of the fossiliferous deposit, it is generally bleached gray to a depth of 2 or 3 feet. This is presumably due to the reducing effect of the carbonaceous material in the fossiliferous deposit.

A singular feature of the mudstone is its apparent total lack of lamination. Even polished surfaces coated with balsam show no trace of the usual depositional structures displayed by fine-grained sediments. They show, instead, a complex "secondary" structure which resembles that of serpentine and which is obviously due, as in the case of the metamorphic rock, to profound chemical alteration coupled with brecciation resulting from volume changes.

It is conceded, of course, that this condition may have been brought about, in considerable measure, by recent weathering; but the same structure was observed in specimens secured by the writer from his deepest test-pits, and it is therefore thought to be due in part, also, to earlier diagenetic changes.

Slickensiding is abundant everywhere throughout the mudstone and occurs in two forms, which are apparently genetically distinct. There are numerous steeply inclined, but relatively flat, surfaces—commonly more or less coated with manganese oxides—that seem to be the result, chiefly, of settling; and, in addition to these, there are myriads of irregular little cone-shaped surfaces, occurring all through the mudstone, that seem to have been caused by internal swelling. The slickensides, of course, are all of secondary origin.

Textural analyses of typical samples of the mudstone reveal little more than a consistent limitation in the range of particle size to dimensions that fall within the silt and clay categories.[8] After dispersion by standard methods[9] all but a fraction of a per cent of each sample was found to pass readily through a $\frac{1}{16}$-mm. sieve—and under the microscope, even this insignificant fraction of a per cent proved, in every instance, to be composed mainly of undissociated aggregates.

For the sake of thoroughness the writer executed a number of pipette analyses on mudstone samples; but the results of these analyses are felt to be hardly worth presenting here, as the size-frequency distribution obtained by rudely dissociating an indurated mud after 200 million years of diagenetic alteration can scarcely be expected to correspond very closely to the size-frequency distribution possessed by the mud at the time of its deposition.

As at many other localities in north-central Texas, the mudstone contains, at Mabelle Draw, a remarkable assortment of different kinds of concretions. They seem to be roughly divisible into two main types, which may be called, for the sake of convenience, the "nodule" type and the "seam" type, the former being isolated, potato-like structures, and the latter, more massive, tabular affairs running either slantwise or horizontally through the mudstone.

Seam-type concretions occur most

[8] See C. K. Wentworth, "A Scale of Grade and Class Terms for Clastic Sediments," *Jour. Geol.*, Vol. XXX (1922), pp. 377–92.

[9] The methods and apparatus used in making these analyses are described in W. C. Krumbein and F. J. Pettijohn, *Manual of Sedimentary Petrography* (New York: D. Appleton-Century Co., 1938), pp. 48, 53, 56–68, 166–68.

abundantly in the first 8 or 10 feet of mudstone immediately subjacent to the limestone layers and, like the latter, are buff-gray in color. Individual seams are commonly 3 or 4 inches thick and may extend laterally, or lengthwise, for several feet—though seams of this size are seldom unbroken or continuous throughout the whole of their extent. Externally, the seams are generally "swollen" in appearance and crisscrossed with fine creases. They may also be pock-marked with tiny pits—like the pits on the opposing surfaces of a stylolite. Internally, they consist of compact, cryptocrystalline, gray calcite with a generous admixture of clay. Some of the larger specimens contain small "shrinkage" cavities,[10] which are generally half-filled with a residual white powder of clay. The powder not infrequently conceals a few clear crystals of barite. Polished sections reveal the presence of numerous fine cracks connecting the internal cavities with the exterior. No traces of any recognizable growth structure are visible.

Concretions of the nodular variety seem to be distributed in an entirely random manner. Some portions of the mudstone are full of them; elsewhere, not a single specimen can be found. They range in size up to the dimensions of a cantaloupe but are generally less evident than the seam-type concretions, since they are usually of the same color as the surrounding mudstone. A variety of surface textures occur. Some, especially the smaller ones, are smooth; others are covered with a reticulate fencework of thin ridges or with oölitic, or botryoidal, deposits. Internally, these concretions generally exhibit a geode-like structure. They have relatively large internal cavities, which are angulated and irregular, as if formed by the enlargement of intersecting "shrinkage" cracks like those in the seam-type concretions. The cavities are generally rather heavily crusted over with fine crystals of calcite or dolomite and may contain a few large, wedge-shaped crystals of barite, with perhaps a bundle or two of barite fibers in the middle. The bodies, or shells, consist of coarsely crystalline calcite, dolomite, barite, and siderite and commonly exhibit a certain degree of concentric variation in color, texture, and composition. An occasional specimen may have a shell which is septated by veins of clear crystalline calcite or barite ramifying outward from the interior.

The question of the origin of these concretions and of their bearing, if any, upon the problem of the origin of the fossiliferous deposit is a difficult one and may, for the moment, be held in abeyance. It may be noted at this point, however, that a good deal of the complexity observed among specimens of the nodule type may be due, in part, to very recent diagenetic alterations. The writer has repeatedly noted that nodules which have lain a long time weathering on the surface commonly exhibit a much greater degree of complexity than those which are found *in situ;* that they are more likely to be coated, for instance, with oölitic or botryoidal deposits; and that they possess larger internal cavities with more and larger crystals in them. It may well be that these nodules are continually undergoing modification by the transfer of mineral matter from the inside to the outside as the result of the surface evaporation of capillary water absorbed during wet weather. J. D. Laudermilk[11] has ascribed the formation

[10] Cf. W. A. Richardson, "On the Origin of Septarian Structure," *Min. Mag.*, Vol. LVI (1919), pp. 327–38.

[11] "On the Origin of Desert Varnish," *Amer. Jour. Sci.*, Vol. XXI (1931), pp. 51–66.

of "desert varnish" on boulders to this process; and there seems to be no reason why it should not be equally effective, if not more so, in producing modifications in the structure of relatively soluble concretions and nodules.

The mudstone at Mabelle Draw is singularly devoid of fossils. The only recognizable organic remains which it is known to have yielded so far are a few bones of a small unidentified reptile or amphibian, incased in purple barite. No traces of any plants or invertebrates (including microfossils) have yet been found.

LIMESTONE

Unfortunately, as is the case with most of the limestones in the Clear Fork and Wichita groups, the two layers that figure in the section at Mabelle Draw pinch out and disappear before they reach the marine "Albany" sequence farther south. This circumstance increases, to some extent, the difficulty of correlation; but the remarkable thing, after all, about these limestones, is not that they fail to connect with the "Albany" but that they do persist, in spite of their thinness, over such wide areas. The stratigraphic irregularity and discontinuity of the intervening "redbeds" in many sections is notorious; but it must be conceded that the environment in which the limestones were deposited was characterized, in general, and for the time being at least, by a high degree of geographical uniformity.

The two layers are very similar in their general appearance. They weather into massive, rounded blocks which mantle the slopes below the outcrops for considerable distances. In structure, too, they are almost identical. The upper surface of both layers is generally smooth and featureless, but locally it may exhibit well-defined mud cracks. The lower surface is commonly covered with coarse swellings, which are reminiscent of the swellings observed on the surfaces of seam-type concretions in the mudstone. The rock is fine-grained, soft, porous, and of impure composition. It contains numerous irregular little seams of greenish clay and yields a generous clay residue on digestion with acid. As in the mudstone, all trace of depositional lamination is notably lacking. Invertebrate fossils—or, rather, their empty molds—occur locally in profusion, and they are invariably jumbled together like the pebbles in an edgewise conglomerate, instead of being arranged in regular layers. The larger molds are often found to contain large, yellowish crystals of barite. Cracks and other cavities are commonly discolored by dendrites and limonite stains.

The following species of invertebrates have been identified from the limestone layers at Mabelle Draw:

Anthozoa
Syringopora multattenuata

Pelecypoda
Myalina permiana
Pleurophorus subcuneatus

Gastropoda
Murchisonia terebra
Strophostylus remex

Cephalopoda
Metacoceras dubium
Orthoceras rushense
Phacoceras dumblei

Ostracoda
Knoxina indistincta
Paraparchites oviformis

Examples of these species are figured in Plate I of the writer's dissertation, and systematic descriptions are given in an appendix.

The occurrence of these fossils is taken as proof that, during the intervals of limestone deposition, the site of Mabelle

Draw was covered—intermittently, at least—by marine waters. These waters belonged, presumably, to the Leonard Sea, which at this time occupied a large area in western Texas and eastern New Mexico.[12]

IMBRICATED DEPOSIT

As explained previously, the imbricated deposit is a local one which overlies the fossiliferous deposit and extends for a considerable distance beyond its margins. It is a noteworthy fact that the contact of the imbricated deposit with the underlying fossiliferous deposit is distinctly disconformable. A considerable portion of the upper part of the fossiliferous deposit was apparently eroded away before the bulk of the imbricated material was laid down. The imbricated deposit also contains disconformities within itself; but its contacts with the mudstone, in general, are conformable.

Owing to the superior resistance of its partially indurated sandstone layers, the imbricated deposit has remained at the surface over wide areas where the mudstone has been stripped away, and its structural features are therefore well displayed. In the thicker sections around the margins of the fossiliferous deposit, where the imbricate structure is best developed, the individual layers are generally inclined northward at an angle of about 5°. There is much local variation, however, for one set of imbricated layers is often found to truncate another set along the strike, and reversals of dip are not uncommon. Where the deposit is thinner, overlying the fossiliferous deposit, there is less regularity of structure; and individual layers may be lenticular or may curve upward and truncate one another in a manner suggestive of eolian cross-bedding. It is not unusual, at some places along the contact, to find large and small lenses of "imbricated" material more or less buried in the fossiliferous deposit.

An outstanding minor feature of the structure of the imbricated deposit is the remarkable prevalence of ripple laminae. At least 60 per cent of all the material in the imbricated deposit seems to have been laid down in ripple structures. Each successive lamina is generally truncated by the one next above; and it is rather difficult, for this reason, to secure any slabs which show the ripples in their original form, but their cross-sectional profiles indicate that both current and oscillation ripples are present.

It is perhaps worth noting that the asymmetry of the current ripples indicates a prevalently southward direction of current movement. This would mean that the northward-dipping imbrication of the deposit as a whole must have been brought about by "hindset" bedding on the currentward, or "stoss," side of the growing deposit. True foreset cross-bedding does occasionally occur within the imbricated layers and invariably runs counter to the direction of imbrication. The writer sees no particular significance in this somewhat unusual arrangement and attributes it merely to local vagaries in current and bottom conditions.

The superior sorting of the imbricated deposit, compared with the fossiliferous deposit, has already been noted. Layers of coarse and fine material may be intricately interlaminated, but they are almost invariably distinct—whereas, in the fossiliferous deposit, clay, silt, and sand are thoroughly intermingled.

Texture histograms of material from the sandier layers of the imbricated deposit indicate a high concentration of

[12] For correlation, and paleogeographic map, see Charles Schuchert and C. O. Dunbar, *Historical Geology*, Part II of *A Textbook of Geology* (4th ed.; New York: John Wiley & Sons, 1941), pp. 274, 283.

particles in the $\frac{1}{8}$–$\frac{1}{16}$ and $\frac{1}{16}$–$\frac{1}{32}$ mm. brackets and an almost total absence of material coarser than $\frac{1}{8}$ mm. There is commonly a secondary mode in the clay range, which appears to be due to sampling across laminae. Nearly all the coarser particles are well-rounded quartz grains. The significance of these features may best be appreciated by comparison with the textural characteristics of the fossiliferous deposit, which are discussed on a subsequent page.

The imbricated deposit, by comparison with the fossiliferous deposit, is relatively barren of the remains of organisms, though it does, here and there, yield a worn bit of bone or the rough impression of a twig, stem, or leaf.

The most interesting fossils yet found in this deposit are some unusually large footprints, which are preserved as casts on the undersides of slabs of sandstone (Fig. 8 of the writer's dissertation). These footprints are believed to be larger than any hitherto described from the Texas Permian[13] and were presumably made by one of the larger species of tetrapods represented by the bones in the fossiliferous deposit. Unfortunately, no "trails" have yet been found—only individual tracks. The footprint casts are accompanied by casts of stem impressions, rill marks, and mud cracks, which are interpreted as indications of recurrent withdrawals of the water in which the imbricated deposit was being laid down.

DESCRIPTION OF FOSSILIFEROUS DEPOSIT

The fossiliferous deposit, as previously noted, is of strictly local extent. Its rather complicated contact with the overlying imbricated deposit has already been discussed. The lower contact, in contrast to the upper one, is simple and easily recognizable, though "camouflaged" to a certain extent by the bleached condition of the adjacent mudstone. The contact is actually exposed for only very limited distances along the creek bottom (Fig. 2), but enough is visible to reveal its character: a distinct disconformity cutting a broad, shallow channel in the underlying mudstone.

The internal structure of the fossiliferous deposit, though obliterated on weathered slopes, may be observed in detail in the numerous exposures which are kept fresh by the undercutting meanders of Mitchell Creek. In general, it may be said that the structure is much less regular and less clearly defined than that of the imbricated deposit. In some exposures it is of the type which has been described as "cut-and-fill" structure; but elsewhere there is only a vague sort of horizontal "bedding," with much interfingering and intergrading of the various ill-defined layers.

The writer was unable to find in the fossiliferous deposit any foreset crossbeds or other structures indicative of the direction of current flow. Even the ripple marks—so conspicuous in the overlying imbricated deposit—seem here to be altogether wanting.

As might be expected, from the indistinctness of its bedding, the fossiliferous deposit yields texture histograms which indicate a very low order of sorting. In other respects these histograms bear a rather striking resemblance to those derived from the imbricated deposit. Like the latter, they exhibit a notable scarcity of particles coarser than $\frac{1}{8}$ mm. and a decided concentration of particles in the $\frac{1}{8}$–$\frac{1}{16}$ and $\frac{1}{16}$–$\frac{1}{32}$ mm.

[13] Cf. R. L. Moodie, "Vertebrate Footprints from the Texas Redbeds," *Amer. Jour. Sci.*, 5th ser., Vol. XVII (1929), pp. 352–68; also *idem*, "Vertebrate Footprints from the Texas Redbeds, II," *Jour. Geol.*, Vol. XXXVIII (1930), pp. 548–65.

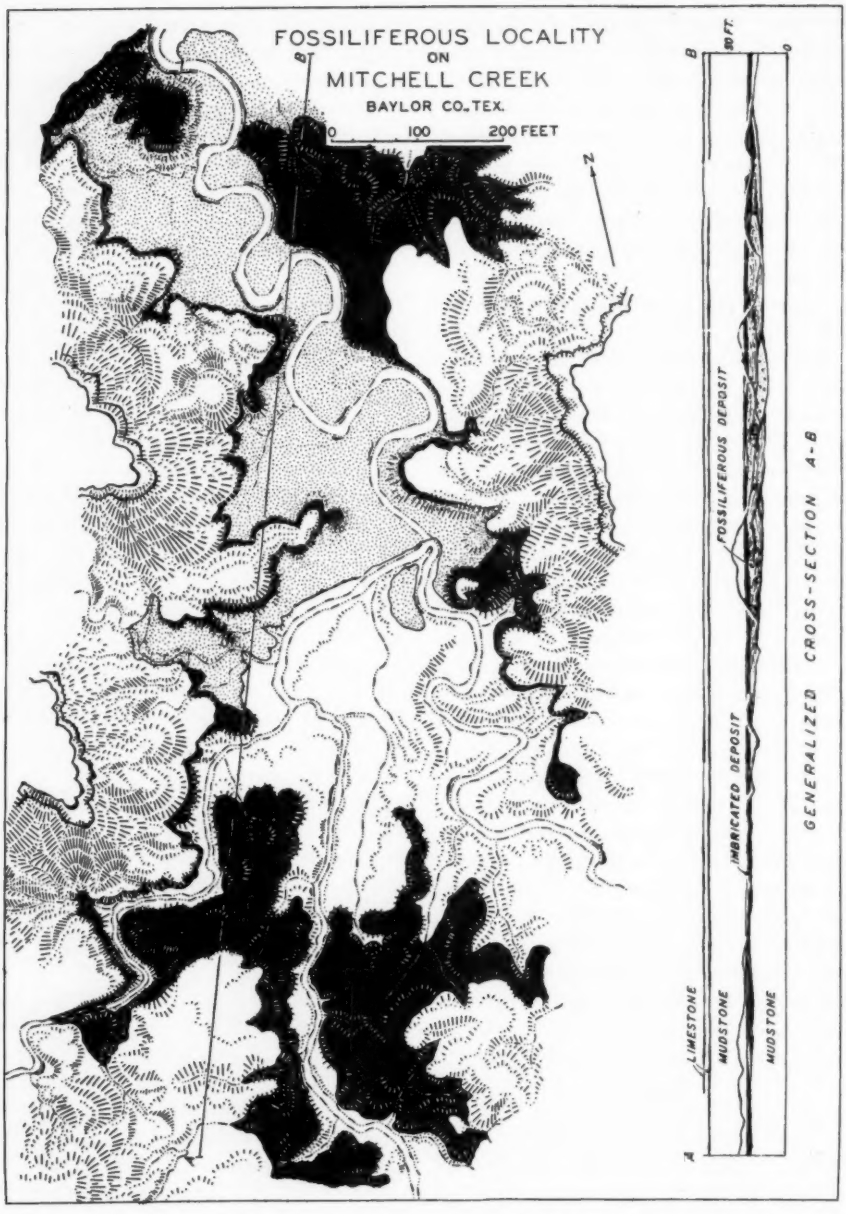

FIG. 2.—Geologic map of Mabelle Draw, showing outcrops of fossiliferous deposit (stippled), imbricated deposit (black), and limestone layers (thin black lines around rim of draw). Remainder of exposed material is mudstone.

brackets. It is noteworthy, also, that the fine sand particles from these two deposits are almost indistinguishable as regards composition, surface texture, sphericity, and roundness.

The general restriction in particle size to diameters of less than $\frac{1}{8}$ mm. is somewhat anomalous, in view of the fact that the fossiliferous deposit contains several isolated lenses of conglomerate with pebbles ranging up to the size of hens' eggs. The "pebbles," to be sure, are not of the ordinary variety, and it was thought at first that they might be merely hardened mudballs. They consist, however, of dense, gray, argillaceous calcite, without a trace of mudball structure, and give every evidence of having originally been concretions, like those which now occur in such abundance in the surrounding mudstone. Many of them even contain "shrinkage cracks," which are like those in the seam-type concretions except that they are commonly lined with pyrite, galena, and other sulphides, instead of with barite. This difference, however, may merely indicate that—while growth of the concretions began during, or soon after, deposition—the mineralization of their internal cavities did not take place until after some portions of the mudstone had been re-worked into new deposits.

At all events, the presence of these pebbles would seem to prove that the otherwise fine texture of the fossiliferous deposit is more the result of fineness of the available sediment than of any lack of transporting power in the currents which were there to carry it.

The pebble bars, while deposition was going on, seem to have functioned as traps for miscellaneous organic fragments. The nooks and crannies between the pebbles are full of odds and ends of bone fragments, teeth, coprolites, bits of carbonized wood, and shells of invertebrates. Unfortunately, most of this material, though well preserved, is rather hard to get at, since the lime-rich pebble layers are now firmly cemented together into solid masses of conglomerate.

Vertebrate remains are abundant in various portions of the fossiliferous deposit. All the material is disarticulated, and much of it is broken and waterworn. Many specimens are incrusted with gypsum. The color of the bone is usually black or bluish black.

The genera which have been identified from this material are as follows:[14]

Reptilia
Diadectes
Dimetrodon
Ophiacodon

Amphibia
Cricotus
Eryops
Trimerorhachis

Pisces
Acrolepis
Pleuracanthus

It will be noted that all these genera, with the possible exception of *Acrolepis*, are regarded as fresh-water, or terrestrial, in habit. Their presence in the fossiliferous deposit clearly indicates that this mass of sediment was brought in—if not actually laid down—by fluviatile agencies.

There are also many plant remains in the fossiliferous deposit, ranging from the most delicate leaf structures to massive stumps and logs.

The leaves—along with twigs, stems, seeds, cones, etc.—are locally very abundant and appear to have been drifted together in patches of slack water before

[14] Examples of the material referred to these genera are figured in Plate II of the writer's dissertation, and systematic descriptions are given in an appendix.

burial. Much of the material was apparently rotten and more or less macerated; but a portion of it which was not too badly battered to begin with has come down to the present in an excellent state of preservation. It is all carbonized, of course, and very much compressed; but the writer has found some leaf structures so little altered that they could be lifted intact from the layers of sediment in which they were preserved. Unfortunately, the best specimens commonly occur in seams of very fine, pure clay which checks so badly on drying that it is extremely difficult to handle.

Quite a number of the leaf specimens have been identified as belonging to recognized species of land plants, which are as follows:[15]

Pteridospermophyta
Brongniartites? yakiensis
Gigantopteris americana
Odontopteris newberryi
Pecopteris tenuinervis
Taeniopteris coriacea
T. newberriana

Coniferophyta
Cordaites principalis
Paleotaxites praecursor
Walchia piniformis

The logs and stumps are scattered in a haphazard manner which seems to indicate that they too were drifted in and did not grow in the places where they were buried. Some may have been transported for considerable distances, for they were apparently stripped of all leaves and branches and most of their bark before finally coming to rest. The larger logs may be 8 or 10 feet long and seem to have come from straight trunks averaging about 8 inches in diameter. All are now more or less oval in cross section, owing to compression by the weight of overlying sediments.

Unfortunately, none of the specimens studied by the writer have retained enough of their original stelar morphology to permit accurate identification. In many, the original cell structure has been almost completely obliterated by the growth of calcite spherulites.

A number of short sections of petrified pith have been found which are covered externally with slender rhomboidal bosses in crossed spiral rows. A. C. Seward[16] mentions various pith casts from the Permian of Europe which exhibit a surface pattern of this type and refers them to the form-genus *Schizodendron*. This name was originated by Edouard d' Eichwald,[17] in 1860, who thought that the casts in his possession represented complete trunks and interpreted the rhomboidal areas as leaf scars. Henri Potonié,[18] in 1888, showed that these areas correspond to the inner ends of medullary rays in the surrounding xylem and that the groove at the bottom of each one of them was occupied by an outgoing leaf trace.

Schizodendron piths have been attributed by various authors[19] to *Walchia;* but there is, as yet, no definite proof of this connection, and they may belong to any of several genera of Permian coniferales which had spirally arranged leaves.

In sum, it may be said that the evidence afforded by the plants is such as to indicate that the sediment in the fos-

[15] Examples of these species are figured in Plate II of the writer's dissertation, and systematic descriptions are given in an appendix.

[16] *Fossil Plants* (Cambridge: University Press, 1919), Vol. IV, pp. 282–86.

[17] *Lethaea Rossica* (Stuttgart: E. Schweizerbart, 1853–68), Vol. I, pp. 265–68, Pl. 18, Fig. 10, and Pl. 20, Fig. 11.

[18] "Die fossile Pflanzen-Gattung Tylodendron," *Jahrb. kgl. preuss. geol. Landesanst.* (1888), p. 311.

[19] For discussion and bibliography, see Seward, *op. cit.*, pp. 285–86.

siliferous deposit came from a river large enough, and persistent enough, to have supported a considerable fringe of perennial vegetation in a region whose general aridity is attested elsewhere by the occurrence of extensive salt deposits.[20] It may well be that the annulations in the xylem of the fossil logs are the result of pronounced seasonal fluctuations in water supply—such as are characteristic of large rivers flowing through arid regions today.

In view of all the foregoing evidence in support of a fresh-water origin for the sediments of the fossiliferous deposit, it is rather surprising, at first thought, that the deposit should also contain invertebrate remains of undoubted marine affinities. The most interesting occurrence is that of *Myalina permiana*, a common species of the overlying limestones. Shells of *Myalina* are so abundant in certain portions of the conglomerate masses as to form solid seams 2 or 3 inches thick. The shells are macerated and obviously did not grow in the places where they were buried. There is a possibility that the species may have migrated, like oysters, into the lower reaches of rivers and that the shells were washed down again by the same fluviatile currents which transported the plant and vertebrate remains; but there is at least an equal possibility that they were brought in by marine currents and are indicative of tidewater conditions at the very mouth of the river.

In addition to *Myalina*, the conglomerates also contain a great many shells of a species of *Spirorbis* (which likewise occurs in the limestones). Occasional specimens of these and other species are found in the beds of silt and clay.

[20] For the occurrence of salt in beds equivalent to the Lueders formation, see George H. Norton, "Permian Redbeds of Kansas," *Bull. Amer. Assoc. Pet. Geol.*, Vol. XXIII (1939), pp. 1755–58. For correlation, see C. L. Mohr, "Subsurface Cross Section of Permian from Texas to Nebraska," *Bull. Amer. Assoc. Pet. Geol.*, Vol. XXIII (1939), p. 1708.

INTERPRETATIONS AND CONCLUSIONS

In recapitulation: The limestone layers, with their salt-water fossils, can scarcely be of other than marine origin. On the other hand, the fact that the tops of the layers are mud cracked indicates that deposition must have taken place in very shallow water—probably between high- and low-tide levels. The presence of so much argillaceous material within the limestone layers, as well as above and below them, suggests that the site of deposition was not far from the mouth of some large river. The absence of internal laminations and the edgewise arrangement of the fossils are interpreted to mean that the limestone was originally laid down as a soft lime ooze. The "swollen" condition of the bottoms of the layers is believed to be the result of progressive downward solidification after burial. The continuity and uniformity of the layers, over wide areas, imply commensurate continuity and uniformity in the site and circumstances of deposition.

Most of the foregoing conclusions are based on sedimentological evidence. There are, undoubtedly, certain special attributes of the invertebrate fauna—both individually and collectively—reflecting the influence of certain equally special conditions of the environment which are not sedimentologically recorded. But, in the opinion of the writer, the significance of the individual peculiarities of fossil faunas like this one is not, as yet, sufficiently well understood to permit the drawing of many conclusions concerning the ecological factors responsible for them. It is not even certain, in the first place, that the assemblage which occurs at Mabelle Draw is a true ecological unit.

The nautiloids, for instance, may have been floated in, as empty shells, from regions far removed from their place of burial.

Inasmuch as it has yielded no marine fossils, the mudstone might conceivably be nonmarine. However, its remarkable uniformity over wide areas—coupled with the fact that it is interbedded, in its typical form, with the layers of limestone—is strongly suggestive of a marine origin. In fact, the mudstone may well represent the normal type of marine deposition in this area—the limestone being merely a variation due to some temporary change in the aqueous environment which led to the precipitation of calcium carbonate along with the usual mud.

On the other hand, if the mudstone is marine, its red color and peculiar structural characteristics are not quite so easy to explain. Shallow-water marine muds are generally full of organic matter; and no deposit which contains much organic matter is likely to acquire, or to retain, the characteristics of "redbeds." There are two possible solutions to this enigma: either the mudstone, for some reason, contained very little organic matter to begin with; or else it lost most of what it once did contain, by aeration before burial. In the writer's opinion, the second alternative is the correct one. It is true that there are very few fossils in the mudstone, and this circumstance might seem to favor the other possibility. But the limestone is full of fossils and is thought to have been deposited under much the same circumstances as the mudstone; so it seems more plausible to assume that the organic material was originally present but that it was "baked out," or destroyed by bacteria, when the mud flats were exposed to the heat of the sun at low tide.

The removal of shells and other hard parts cannot, of course, be ascribed to aeration and must be attributed to subsequent solution by ground water. It will be recalled, in this connection, that the shells originally in the limestone are represented only by casts. In view of this fact, it does not seem unlikely that any shells which were originally present in the relatively unindurated mudstone might have disappeared without leaving a trace.

The hypothesis of a littoral origin for the mudstone has so far been based primarily on indirect evidence from the limestone. Additional evidence in its support is found in the imbricated deposit, where mudcracks, footprints, rillmarks, and scattered lenses of material cross-bedded in the eolian manner, occur among layers with abundant ripple marks and other evidences of the aqueous environment. There is no direct proof, in the case of the imbricated deposit, that these waters were marine; but the structural features of the deposit are precisely those which are produced by the transporting agencies which presumably operated, though with different materials, during the deposition of the limestone and the mudstone. These agencies would have been waves and currents at high tide and the wind at low tide. If the fossiliferous deposit was here first, as it obviously was, to provide the material to be re-worked over the surface of the mudflats, there is nothing about the imbricated deposit which does not fit perfectly into the concept of a littoral environment. The presence of isolated lenses of imbricated material below the top of the fossiliferous deposit would merely indicate that the process of re-working was already under way before deposition of the fossiliferous deposit had been completed.

The absence of invertebrate remains is here attributed, as in the case of the mudstone, to the solutional effects of groundwater. To explain the absence of molds in the indurated sandstone layers, it is only necessary to assume that solution took place before induration.

The fossiliferous deposit, with its abundant remains of terrestrial organisms, must obviously have been derived from fluviatile sources. It might possibly have been laid down by littoral currents off the mouth of some river, but the structure and texture of the deposit are such as to indicate that the river was still in control when final deposition took place. The "cut-and-fill" bedding and imperfect sorting are almost certainly the work of shifting and fluctuating stream currents, rather than the more uniform currents of the sea.

If actually a stream did cut across the tidal mud flats in this locality and gouged out a shallow channel to be filled subsequently with the sediments of the fossiliferous deposit, as the evidence seems to indicate, this stream can have looked like an ordinary stream only at low tide. At high tide it must have been merely an offshore fluviatile current, precariously held to its usual course by the confining influence of its own submerged levees. As deposition progressed and the original channel gradually silted up, the influence of the levees must have lasted long enough to have permitted aggrading of the stream bottom to a level higher than that of the surrounding mudflats. Thus, when the channel was finally abandoned, a long, elevated mass of river material would have been left behind, to be reworked slowly by the waves and currents of the littoral zone.

The sudden appearance of a sizable stream and its subsequent disappearance may best be attributed to the temporary opening-up of a new distributary at the mouth of some large river. Such occurrences are common in present rivers during times of flood, and, indeed, the "fresh" appearance of so many of the plant remains may well indicate that they were torn off by a storm rather than dropped off in the normal course of withering and decay.

In summation: If the writer has correctly interpreted his evidence, the fossiliferous deposit at Mabelle Draw is to be regarded as the product of a brief episode of fluviatile activity interrupting the normal progress of marine deposition in an extended littoral environment. The available data do not permit a precise cartographic reconstruction of the scene in which this event took place, but it may safely be assumed that the general physiographic background was not greatly different from that along certain portions of the Gulf Coast of the United States today. The "gulf," in this case, was the Leonard Sea; and the adjacent coastal plain was the western margin of an interior lowland which was bordered, on the south and east, by mountains much younger and far more rugged than the present Ouachitas and Appalachians. The climate was more arid, and the vegetation and animal life more primitive; but, in spite of these differences and the changes wrought by time, the sediments of Mabelle Draw seem to be fundamentally similar to those forming at the mouths of numerous rivers which today are weaving the record of their existence into the voluminous mud flats of the Gulf.

RECENT DEPOSITS OF VESICULATED MUD ALONG SOUTHWESTERN OHIO STREAMS

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ABSTRACT

Calcareous silts deposited along streams of southwestern Ohio contain a large proportion of finely divided, partly digested organic matter, mainly sewage. Desiccation is attended by vesiculation as gases are generated by organic decomposition and by reaction of organic acids formed during decomposition with carbonate present in the mud.

INTRODUCTION

Recent muds deposited on bars and banks of certain streams in southwestern Ohio contain very numerous small, irregularly shaped, unconnected cavities. Examination of the literature has failed to yield any references to similar features either in unconsolidated sediments or in rocks. Therefore, it is believed that a description of the features observed, together with theories as to their probable origin and geological significance, is justified.

NATURE OF THE MUD DEPOSITS

Mud deposits containing cavities occur at many places along the Ohio, Miami, and Little Miami rivers and along certain of their tributary streams. Only those localities which have been examined in considerable detail are shown on the index map, Figure 1, *I*.

The muds are recent stream deposits that have accumulated on banks and on portions of bars. At the time of field examination the muds were exposed subaerially to a height of about 3 feet above pool stage. In places that would be exposed to reasonably vigorous current action during rising water only a single layer of mud is present, previous layers having been scoured before deposition of the most recent mud. In the somewhat protected areas, however, several layers of mud may be present in a single vertical section. Of the localities described, only at No. 1 is there more than one layer present.

A typical occurrence is that along the Miami River near Miami, Ohio. Here, as is shown in Figure 1, *II*, a gravel bar is tied to the somewhat higher flood plain by deposits of poorly sorted sand and gravel. Along the downstream end of the gravel bar, in the protected swale between the bar and the flood plain, and along the bank downstream from the bar, mud has accumulated to a maximum measured depth of 10 inches. A section measured at point *A* is shown in Figure 1, *III*. Streamward from an elevation slightly below *A* the layer *a* is covered to a depth of about $\frac{1}{4}$ inch by a black malodorous slime. The slime contained a number of large gas bubbles. Material of this sort was found at no other locality. Irregular polygonal mud cracks occur in the hardened mud of layer *a*. Fast-growing vegetation of several different types is locally abundant. Cavities are present throughout the deposit and are especially abundant in layer *a*, where it is from 6 to 10 inches thick. A few cavities are present in layer *b* but apparently are modified by compaction.

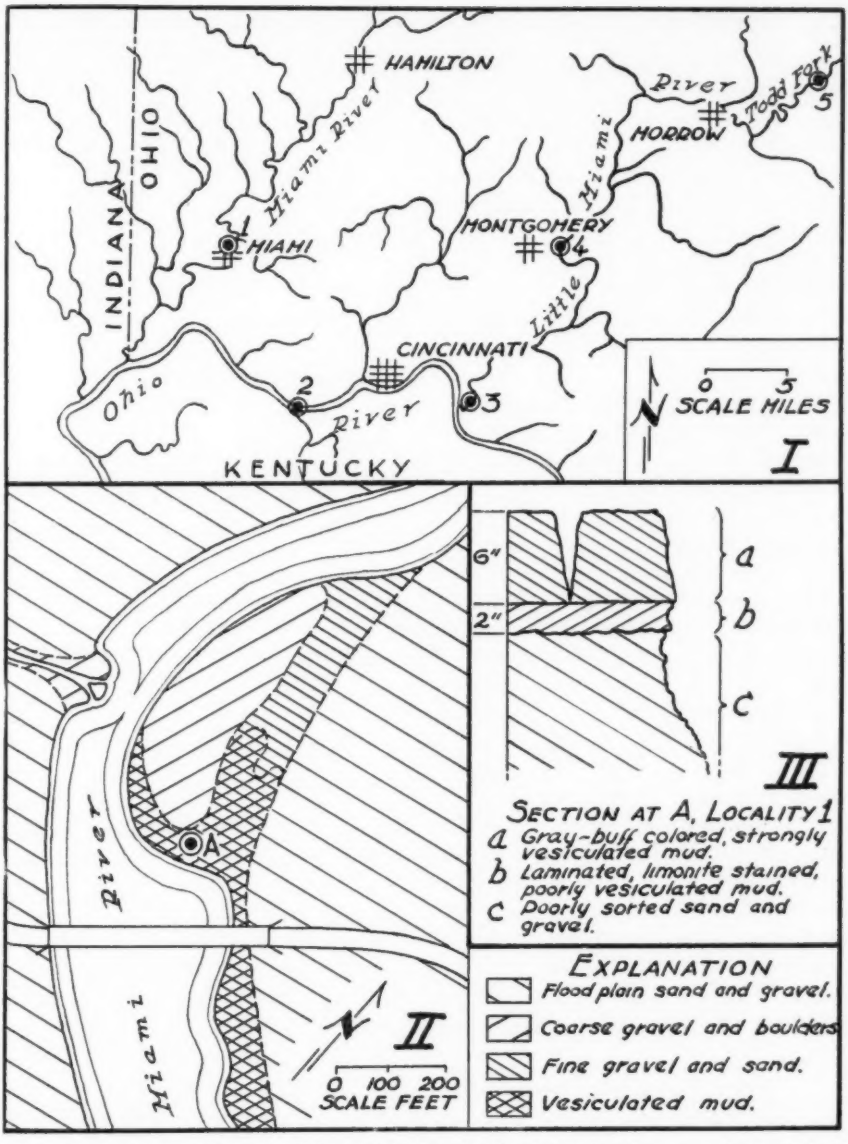

FIG. 1.—*I*, index map showing localities at which deposits of vesiculated mud were examined. *II*, sketch map showing surficial deposits at point *A*, locality 1. *III*, section at *A*, locality 1.

DESCRIPTION OF CAVITIES

The general appearance of these structures is shown in Figure 2. In samples where the holes are well developed, as illustrated in Figure 2, *E*, they occur about thirty per square inch, as measured on plane surfaces cut normal or parallel to the bedding. Individual holes average 3.5 mm. in maximum diameter and 1.5 mm. in minimum diameter. The maximum diameter of any hole observed is 10 mm., and minimum diameter is less than 0.1 mm.

Whereas mud from a single locality is rather uniform in the size and spacing of cavities, mud from different places may be quite dissimilar in this respect. In mud where the cavities are not so well developed, they are smaller in size and fewer in number. However, regardless of number and size, the shapes of the cavities are similar. Cavities are about as well developed in the mud at locality 3 as at locality 1. These structures were somewhat poorer at localities 2 and 4 and were poorest at locality 5.

The holes do not extend in an uninterrupted fashion throughout the mud but are separate and unconnected. Although they possess an elongation in some direction, there is usually no common orientation. However, in some layers of mud, such as *b* at locality 1, the long dimensions of the holes have a general horizontal trend which is thought to be due to flattening by compaction.

NATURE OF THE MUD

The mud in which cavities occur is a light-tan to gray-colored calcareous sandy and clayey silt. Carbonate was removed from the silts by treatment with dilute hydrochloric acid. Carbonate content is shown in Table 1. Size analyses of carbonate-free samples are plotted in Figure 3.

TABLE 1

CARBONATE CONTENT OF MUD SAMPLES

Locality	Carbonate Content (Percentage)
1 (layer *a*)	11.0
1 (layer *b*)	22.4
4	43.5
5	46.4

THEORIES OF ORIGIN OF CAVITIES

The theories that have been considered in attempting to explain the origin of the cavities are listed below:

1. Worm burrows
2. Action of plant roots
3. Desiccation
4. Vesiculation due to—
   - *a*) Escape of occluded air
   - *b*) Escape of air trapped by resubmergence of desiccated mud
   - *c*) Escape of carbon dioxide generated from calcite present in mud by—
     - i) Natural organic acids
     - ii) Acids derived from sewage and/or industrial waste products
   - *d*) Escape of carbon dioxide, methane, and/or other gases generated by decay of—
     - i) Natural organic material
     - ii) Sewage
     - iii) Industrial waste products

Field evidence refutes theories that the cavities owe their origin to burrowing of worms, action of plant roots, or desiccation.

Worm tubes are circular in cross section and are continuous, unlike the irregularly shaped, unconnected cavities here described (see Fig. 2, *B*).

Where present, vegetation has broken and dislocated the layers of mud. Large roots have destroyed the cavities by crushing, and smaller roots leave holes similar in appearance to the worm tubes but somewhat smaller in diameter. Vegetation gives no evidence of having controlled or affected the distribution of the cavities.

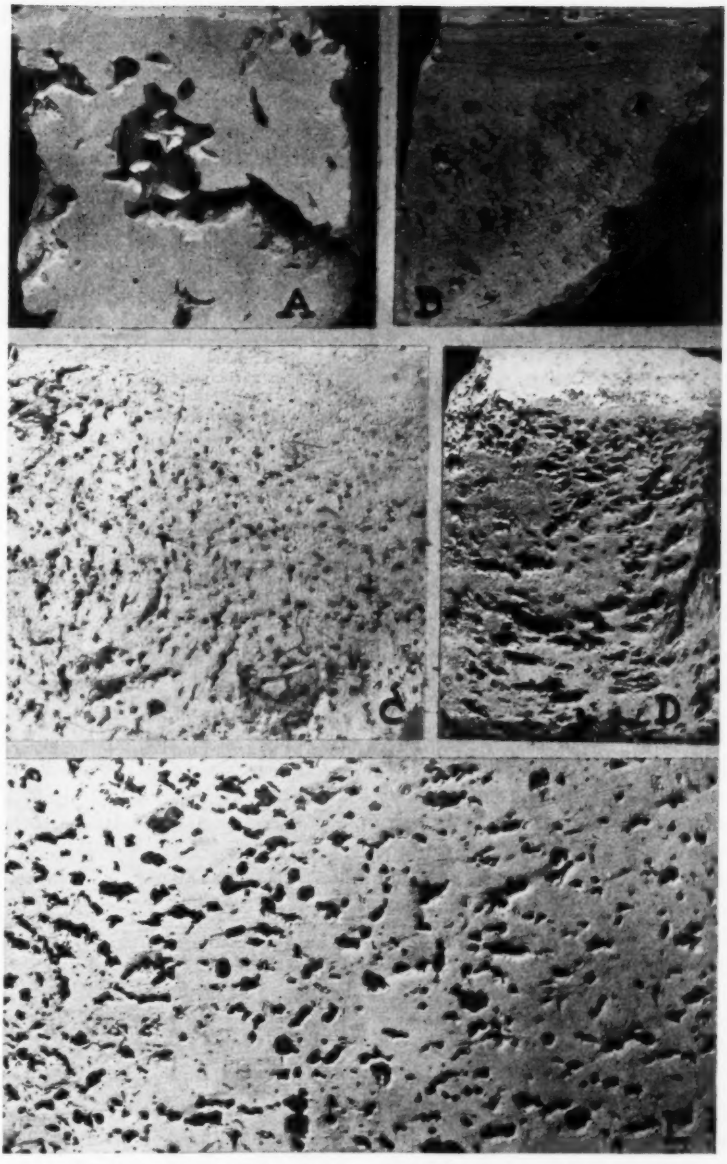

FIG. 2.—Photographs of naturally and artificially vesiculated muds. Surfaces are cut normal to the bedding of naturally occurring muds and vertically through the mud cylinders produced in experiments. All photographs are natural size. *A*, Exp. 8; calcareous mud (Minford silt) plus apple cider. *B*, locality 5 (see index map, Fig. 1, *I*). *C*, locality 4; narrow, dark-gray streaks, roughly horizontal, are sections of partially decayed leaves and grasses. *D*, Exp. 10; black slime from locality 1; rude orientation of vesicles is due to compaction in beaker. *E*, locality 1, layer *a* (see section, Fig. 1, *III*).

Cavities are exposed in the sides of mud-cracked blocks. This indicates that they were developed before the cracks, and it is not likely that both owe their development to a common process.

The validity of several other theories has been tested by a series of laboratory experiments, the nature and results of which are presented in Table 2.

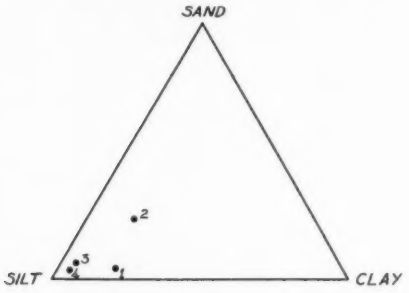

FIG. 3.—Triangular diagram showing textural composition of carbonate-free mud. Sand—material greater than $\frac{1}{16}$ mm. in diameter; silt—material between $\frac{1}{16}$ and $\frac{1}{256}$ mm. in diameter; clay—material less than $\frac{1}{256}$ mm. in diameter. No. 1—locality 1, layer *a;* No. 2—locality 1, layer *b;* No. 3—locality 5; No. 4—locality 4.

In the first nine experiments the muds were wet to saturation, poured into 250-ml. beakers, and allowed to dry at room temperature. In Experiment 10 the black slime was allowed to dry without dilution. Whenever acid or cider was added, 20-ml. lots were stirred into the beakers containing the water-wet mud.

DISCUSSION OF EVIDENCE BEARING ON THEORIES

Minute globules of air adhering to clastic materials may be deposited with them and trapped in the sediment thus formed. Such occluded air would tend to be expelled from the sediment by compaction and by buoyancy. In a rapidly hardening mud some air bubbles might be preserved as cavities. It is unlikely, however, that enough air would be present, and in bubbles of sufficient size, to account for the great number of holes in the muds here described. Furthermore, drying of mud under laboratory conditions, as in Experiments 1 and 2 of Table 2, failed to produce the structures observed in nature.

TABLE 2

EXPERIMENTS IN SYNTHESIS OF CAVITIES

No.	Material	Results	Nature of Cavities Produced
1...	Calcareous mud* and tap water	−	
2...	Noncalcareous mud† and tap water	−	
3...	Miami River mud (layer *a*) and tap water	+	Numerous very small round holes
4...	Calcareous mud and 1:10 acetic acid	+	A few small ellipsoidal holes
5...	Calcareous mud and 1:100 acetic acid	+	A few very small ellipsoidal holes
6...	Noncalcareous mud and 1:100 acetic acid	−	
7...	Calcareous mud and filtrate from Miami River mud‡	−	
8...	Calcareous mud and apple cider	+	Similar in shape but larger than natural cavities
9...	Noncalcareous mud and apple cider	+	Similar in shape but smaller than average natural cavity
10...	Black slime from locality 1 (nothing added)	+	Similar in size and shape to natural cavities

* Minford silt.

† Minford silt treated with dilute hydrochloric acid, washed, and filtered.

‡ Filtrate secured by filtering Miami River mud after heating in excess of water for ½ hour.

Air might also be trapped in a dried mud deposit and expelled through the softened mud or even through a new deposit in a manner similar to that outlined above. Where older layers of mud are found, cavities are few and flattened

somewhat by compaction. Where no underlying mud layer is present, however, expulsion of air from it could not possibly have been a factor contributing to a vesiculation of a new deposit. In most localities there is only a single layer of mud, and this very commonly is strongly vesiculated.

There is left, then, only the possibility that gases generated by biochemical and/or chemical action formed the holes. Only after considerable compaction would the mud be of sufficiently high viscosity to prevent or inhibit the escape of gases. On the other hand, vesiculation was complete before desiccation was advanced enough for mud cracks to develop.

Acidic industrial waste products or sewage acids would react so promptly with the carbonate, while this was still in suspension, as to be rapidly neutralized; and no effervescence would occur after deposition. Therefore, this type of acid is of no importance in the process of vesiculation.

It is considered likely that gases generated in the mud after its deposition were responsible for vesiculation. Such gases might be generated by organic decay or possibly by reaction of organic acids formed during decay with carbonate in the mud. In Experiment 10, Table 2, the black slime found at locality 1 dried under laboratory conditions to a light tan-colored vesiculated mud almost identical in appearance with the mud of layer *a*, locality 1 (cf. photographs *D* and *E*, Fig. 2). Accordingly, it is thought that soon after its deposition all of the mud now vesiculated became similar in composition to this slime. The latter material, when fresh, consists principally of finely divided detrital mineral grains. The black color is due to iron sulphide, which alters to limonite during drying but is of no moment in the process of vesiculation. Examination of the slime by Mr. Aureal Cross, of the department of botany, University of Cincinnati, disclosed a very high content of organic matter, only a small part of which showed recognizable cell structure. The rather complete digestion of the organic matter and the presence of quantities of blue-green algae are indicative of a rather large proportion of sewage. Such material is added to the streams at a number of cities and towns in Ohio. Deposits of strongly vesiculated mud may be correlated roughly with their location on streams draining the more populated areas.

The role of sewage in vesiculating the mud in which it occurs lies in the generation of gases such as methane and carbon dioxide by organic decay. In addition, there are formed some organic acids as a result of decay. These attack the carbonate of the mud and generate additional quantities of carbon dioxide. This reasoning is supported by laboratory data. Relatively stiff calcareous muds were mildly vesiculated in Experiments 4 and 5, Table 2, after introduction of acetic acid. In Experiments 8 and 9 fermenting apple cider was added to calcareous and to noncalcareous mud. Although vesiculation resulted in either case, the effect was much stronger in the calcareous mud. Furthermore, since Table 2 shows a lower percentage of carbonate in the more strongly vesiculated muds, apparently some of the carbonate has been destroyed to produce carbon dioxide. These facts indicate that, while vesiculation may result from simple organic decomposition, carbon dioxide generated from carbonate by the action of organic acids is an important factor.

When deposited, the muds are rich in organic matter—mainly sewage—and

may be colored by industrial waste products, such as iron sulphide. The organic matter is finely divided, partly digested, and in process of decomposition. Gases escape freely until the mud is sufficiently compacted to inhibit their escape. As the mud is exposed subaerially, it becomes increasingly viscous, owing to drying and compaction, until the gases no longer escape but collect into large spherical bubbles. Upon complete desiccation of the mud the bubble holes or vesicles shrink and become quite irregular in shape.

CONCLUSIONS

The deposits of mud along certain streams in southwestern Ohio owe their vesiculated structure to gases generated in the sediments after deposition and before pronounced desiccation. The gases are decomposition products of organic matter, mainly sewage. In addition, carbon dioxide formed by action of organic acids on carbonate is a factor.

Since sewage is the important gas-generating material in the deposits here described, the results obtained may be considered of limited occurrence and of little geological significance. However, the generation of gases in sediments of high organic content has long been recognized. It is not at all improbable that organic debris, exclusive of sewage, might assume the role of sewage in gas generation in deposits similar to those described here.

In most highly organic sediments the gases generated by organic decay are able to escape freely. The formation of vesicles is likely to occur where the mud is exposed subaerially, for only under this condition does it become sufficiently viscous to prevent or inhibit the escape of gases. Most of the vesicles probably would be destroyed by erosion or compaction. Some, however, might be preserved by filling and may occur as primary structures in some sedimentary rocks.

ACKNOWLEDGMENTS.—The writers are indebted to Dr. Rousseau H. Flower for the photographs and to Professor John L. Rich for a critical reading of the manuscript.

SOME WRONG WORDS

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Most of us are fond of high-sounding words, sesquipedalian and exotic. In the jargon of ore deposition, we hitch the prefix of position, *epi* ("upon, above"), to the adjective of condition, *thermal* ("of or pertaining to heat, warm"), a senseless combination that gives no clue to its employment for "formed at low temperature." Nor are *mesothermal* and *hyperthermal* felicitous plays with the language that "had a word for it." Would it not suffice to say: "low-temperature," "moderate-temperature," and "high-temperature deposits"?

Some misspell *epanticlinal* by forgetting that *epi* becomes *ep* before a vowel. Commonly they place a hyphen after *epi*, but this retains the wrong sound and is not correct use of Greek.

Many misplace the prepositional phrase in "faults *en échelon*" by clumsily writing "*en échelon* faults," which is like saying "the in-step soldiers" for "the soldiers in step." Some nicely avoid this trouble by the Anglicized "echelon faults" (written without accent).

The redundancy in *ptygmatic fold* ("foldlike fold") makes it doubly say what is not intended, if an author means that a little magmatic sheet was intruded with convolute form, not folded later with the enclosing rock. He means a *ptygmatic* ("foldlike") *injection*. It is unfortunate that "ptygmatic" commonly is misapplied, also, to complex, but true, "flexural folds" and "glide-folds" (shear-folds). These, unlike injectional structure, laterally affect the invaded rock for a considerable distance from the little sill or dikelet, and their limbs are more greatly thinned.

The writer suspects that *ptygmatic injection* may occur during a stage of metamorphism when the enclosing rock is relatively so weak that it loses control over an advancing, thin sheet of hardening magma. Before intrusion in this form ceases, the magma may stiffen, possibly until its viscosity exceeds that of the country-rock. The stronger, forward part of an intruding, tiny sill would then be pushed and crumpled by the further advance of the weaker, less congealed parts behind it, or the latter might crumple the more. In either case the push would be magmatic, and the longer parts of the curved axes of the *injectional crumples* (as they might well be called) would tend to be normal to the direction of intrusion. An axis of this kind may bend so diversely that it does not lie in a plane, and the term "axial plane" cannot then be used. Evidently, we should solve the difficulty of finding the mean orientation of these axes with reference to the general fabric. The immediate purpose, however, is not to discuss a problem but to illustrate the need of finding the word (here, *injection*, not *fold*) that should go with another word (here, *ptygmatic*) and to reveal the greater clarity of the less exotic expressions, *injectional crumple* and *convolute injection*.

In the present terminology of solid deformation, the two words, *elastic flow*, seem as incompatible as those in "white

lampblack." They are used for what the present writer calls *the slow element of elastic response* to loading or to unloading. Heretofore, *flow* has been restricted to permanent fine gliding, with or without subsidiary rotation. (Recrystallization and other chemical transfer of material, being nonmechanical, should not be called "flow," which, however, it may promote.) In permanence of result, flow is the opposite of elastic response. Indeed, flow marks the absence or the overcoming of elasticity and, hence, cannot be "elastic." One cannot think of "elastic flow" without mentally destroying the essence of one of the two antithetic words. Some other term may be found for what the writer is content to call "the slow part of elastic reaction."

The term *obsequent fault scarp* implies that a scarp can "follow against" something; but what can it follow in this strange way? In self-explanatory words it is a *back-facing scarp*.

The term *fault-line scarp* necessarily is applied mainly to scarps that are *not* on fault lines, on which one finds but few old scarps of any kind. A scarp that is due to the greater erosion of one side of a fault may be called an *erosional fault scarp*, preferably with further modification, such as *back-facing* if it faces the upthrow side of the fault or *forward-facing* if it faces the downthrow side, though the latter aspect may be taken for granted, unless the contrary is specified.

As in our older literature and in foreign writing, the term *fault scarp* should again be applied in America to any scarp that is due to the *presence* of a fault, even though the relief in question largely expresses erosion. This commonly is done in many regions, as in England, where they are still known as "fault scarps." In preliminary study (and not rarely in advanced study) finer distinction may be uncertain, and for such cases we need *fault scarp* as a general term, in its broad original sense. Fuller information ultimately may permit more detailed description of the fault scarp, preferably not by creating technical terms but by using adjectives, like those above or others, for example: "multiple," "partly flexural," "sliver-scarp," "like-" or "opposite-facing" (applied to two or more), "fresh," "subdued," "recessional," "twice-renewed" ("three-stage"), "left by differential erosion," etc. Since a *fault-line scarp* generally is not on a fault line, the term is misleading and should be abandoned.

Seeking a Spanish word for "hillside" (such as *falda*, "skirt"), one physiographer miscalled it a *bajada* ("descent"). He must have been going downhill, for travel in the other direction would have made the same place a *subida* ("ascent"). Neither name is appropriate for a topographic form.

Playa recalls the pleasure of diving in the surf of famous beaches, like the Playa del Mar, near Buenos Aires, where also the River Plate has its *playas*. *Playa lake* brings to mind a blue, Altiplanician lake, with shelving shore. Alas, for learned bathers! Physiography limits *playa* to a saltpan (*salina*), or a lacustrine mudflat, which in the wet season may have a central lake, accessible to birds.

Thus limited, as a technical term in English, *playa* is so well established that it must be accepted. Yet, when any foreign word is borrowed, its meaning should not be changed. Confusion arises even at its home, if the word goes back to its original tongue with our redefinition, as may be appreciated, unhappily,

by reading a Spanish translation of a North American text on physiography. The writer believes that, if English fails as the base of a needed term, one should not choose a word from another modern language, unless a current foreign definition fits the required usage. We have no right to abuse a living tongue, the delicacy of which we may not sense. If English fails, it would be better to build new terms, preferably simple, out of the long-suffering Greek or Latin.

The writer confesses that he, too, has made most of these verbal mistakes and that he is not the first to point them out. His aim is simply to write what is mnemonically chrestomathic, not "catachrestically sequaceous."

GERARD DE GEER
1858–1943

With the passing of Baron Gerard De Geer at the end of last July, the *Journal of Geology* lost a very distinguished foreign associate editor. One of the original group when the first issue appeared in 1893, his friendly interest in the *Journal* was still manifested almost at the close of his long, eventful life. Of this, and much more, the editor is feelingly recognizant.

Gerard Jakob De Geer was born in Stockholm on October 2, 1858, in a family whose line goes back to a Dutch merchant who emigrated in 1627 to Sweden, where he became naturalized and later was raised by the king to the nobility. Baron Louis Gerard De Geer, father of the geologist, formulated Sweden's present system of parliamentary procedure and at several times served as a cabinet minister.

In 1877 Gerard De Geer entered the University of Uppsala, intending to become an engineer, but the strong appeal of the natural sciences soon revealed where his greatest interests lay. He was eager to study nature in his own way. That his footsteps took the direction they did is perhaps surprising in view of the fact that, throughout his student days at the University, the professor of geology was absent on sick leave. It happened, however, that the gravelly Uppsala esker which rose above the soggy plains surrounding the town was the only place where young De Geer could walk in the wet spring season without constantly kicking chunks of clay off his boots. Also, for more than a century, eskers had been a subject of much speculation in Sweden, and even Lyell had visited the Uppsala ridge. Thus began one of the outstanding geologic careers of our time.

Eskers had been viewed as beach ridges or sea banks evidencing extensive flooding of the land, an association which led De Geer to undertake careful investigations of Quaternary variations in sea-level and the differential warping of Scandinavia. The results ultimately obtained were among his very important contributions. With the rapid rise of glacial geology, De Geer threw himself wholeheartedly into those intensive studies of Swedish glacial deposits which have proved so extraordinarily fruitful in interpreting continental glaciation and many features of the Quaternary. Most original and remarkable of all was his method of measuring time by piecing strips of annual clay varves together in their proper sequence until the record of years was complete and a definite chronology was established for all postglacial time. The persistence with which this great task was carried to successful accomplishment has few geologic parallels, and none shows more singleness of purpose over so many years. Thereby was written a new chapter in geologic history.

De Geer became senior geologist of the Swedish Geological Survey in 1885; held the chair of geology at the University of Stockholm from 1897 to 1924; was the University's *rector magnificus* (1902–10); and served as pro-rector until his retirement from the University in 1924. Following this, he founded the Geochronological Institute in Stockholm and was its mainspring until his death. He was also a member of the Swedish Parliament (Riksdag) from 1900 to 1905. Five voyages were made to Spitsbergen, and in 1891 and 1920 he visited selected localities in the United States.

Gerard De Geer's prolific scientific writing continued until the end. *Geochronologia Suecica Principles*, one of his most monumental works, is but three years old. The master's mantle falls on Ebba Hult De Geer, his loving scientific partner in all his later expeditions, and on many younger geologists trained and stimulated by him.

ROLLIN T. CHAMBERLIN

REVIEWS

Seismology. By PERRY BYERLY. New York: Prentice-Hall, Inc., 1942. Pp. 256; figs. 57. $4.65 trade, $3.50 school price.

The field of earthquake seismology is covered in two parts: Part I, on earthquakes, which is understandable with little technical knowledge; and Part II, entitled "Seismology," which requires some preparation in mathematics and physics. The first two chapters, "Elasticity and Plasticity," and "Earthquake Vibrations," introduce clearly and concisely the mechanical principles and basic facts needed in preparation for the systematic topical treatment which follows.

The cause of earthquakes is split very properly into separate discussions of the immediate cause and the underlying causes. Both are effective because of the author's discrimination in bringing out with proper valuation the essentials of what may be said to be known and what is still in the realm of hypothesis. The reader's interest is maintained throughout. A few minor slips, however, have escaped detection. Bouguer and the anomaly named for him always appear as "Bougier," and Chimborazo, whose attraction of the pendulum he studied, is not in Peru (pp. 43 and 46). On page 70 the relative displacement on the fault between the well-known Bear Valley dairy-ranch house and the front garden is given as "12 feet (see Fig. 26)." It should be Figure 12*b* (p. 25), and the displacement is there given as 17 feet.

Some may think that too much has been made of the elastic-rebound theory, for it seems to be taken as *the* explanation of the mechanics of faulting. But perhaps it is only because of the author's commendable desire to secure brevity that no other possibilities are considered. The 1906 slip on the San Andreas fault is indeed an excellent example of rebound, but does it follow that elastic rebound is a *complete* theory of earthquake faulting? Faulting is of diverse sorts, and a sudden fault displacement may not necessarily be simply a rebound or fling-back of the opposing surfaces to the extent of the previous elastic strain. To illustrate, one may utilize a few sentences which appear farther on (p. 40) in a good discussion of deep-focus earthquakes.

> A bar of wax clamped at one end in horizontal position will, if given sufficient time, bend down of its own weight. It has insufficient strength to support its own weight. But if one adds weight to its free end, it will break when the load becomes large enough. The loads have been added faster than the plastic flow of the wax may accommodate them.

One cannot say of this case, as the elastic-rebound theory has it, that "all of the energy released at the time of the shock is just before the shock in the form of potential energy of elastic strain in the rocks on either side of the fault." There was much gravitative potential energy in the weights added. Possibly the analogy is not a good one for earth conditions; yet it may be noted that railway surveys showed that the fault movement during the 1929 West Nelson earthquake in New Zealand was a direct forward shove of an active block which rode obliquely upward over a relatively passive footwall.

Chapters on "Effects of Earthquakes," "Distribution of Earthquakes," and "Great Earthquakes" complete the first half of the book. Since much of this material concerns spectacular happenings with strong human appeal, and the writer's style is by no means dry, these chapters are very easily read. Yet the interest is quite incidental to the scholarly scientific handling of a wealth of factual information selected because of its significance.

Part II is technical seismography with the necessary mathematical treatment. Forty-five pages are devoted to the theory, principles, and types of seismographs. The next two chapters discuss elastic waves and the paths of waves and travel-time curves, together with the light which they throw on earth structure. The last two chapters are entitled "Location of Epicenters" and "Seismograms."

As stated in the Preface, the author has directed his efforts toward brevity; naturally, he would not mention clarity; therefore the reviewer will make this claim for him, since clarity of thought and expression characterize the volume. These two qualities help make this a very useful book.

R. T. C.

The Floor of the Ocean: New Light on Old Mysteries. By REGINALD ALDWORTH DALY. Chapel Hill: University of North Carolina Press, 1942. Pp. 177; figs. 82. $2.50.

This interesting, well-written book presents three lectures given by Professor Daly in 1941 at the University of Virginia under the auspices of the Page-Barbour Foundation. In the first lecture the writer discusses "Foundations of the Great Deep"; the second deals with "Submarine Mountains"; and the third describes "Continental Terraces and Submarine Valleys" and discusses the genesis of the latter.

The first two chapters summarize much of the pertinent material in the writer's earlier papers and books. Significant features of the ocean basins and submarine mountains are described, and evidence obtained by geophysical methods is presented. From the available information the writer postulates that the earth has an outer layer of solid rock 50 miles or so in thickness, beneath which is a weak layer that may be vitreous but responds to earthquake waves as if it were solid.

To many geologists and oceanographers the third section will be of greatest interest. There Professor Daly presents much new evidence to support his hypothesis[1] that many submarine canyons were carved during certain stages of the Pleistocene by sediment-laden density currents. Maps of the Hudson, Wilmington, Washington, Norfolk, and Georges Bank canyons, obtained from sonic soundings, are presented. Particularly significant is the intricate topography of the continental slope adjacent to the major canyons. Dr. P. H. Kuenen's model experiments on density currents and recent engineering data on silt-laden underflows in Lake Mead and other United States reservoirs are introduced to show the adequacy of density currents as erosive agents.

GORDON RITTENHOUSE

Structural Geology. By MARLAND P. BILLINGS. New York: Prentice-Hall, Inc., 1942. Pp. xi+473; figs. 336; pls. 19. $4.50.

Structural Geology by Billings is both a very teachable text for class use and a practical reference book for the field geologist who seeks enlightenment on some special phase of the subject. Its emphasis is on principles, methods, and technique, the author having "intentionally refrained from a treatment of the more speculative phases of geotectonics because he believes that such subjects can be intelligently studied only by geologists with a broad background in many fields of geology." Thus his aim has evidently been to prepare a text which builds up solidly from elementary general geology.

Each chapter begins rather simply, so that the student starts with a clear concept, which then develops easily until the whole topic is in hand. All the way through, the statements of fact and principle are about as understandable as it is possible to make them. In fact, the clarity of the explanations is the most notable characteristic of the book. Their effectiveness is also due, in no small degree, to an unusually free use of diagrams skilfully planned by a successful teacher. In various places, where an author might have been content to give a single drawing and leave much to the student's imagination, Billings supplies several diagrams to make sure that the student gets a correct and adequate understanding. These are amplifications rather than repetitions; there is little unessential matter incorporated. Quite helpful in many drawings is the insertion of the strain ellipse, even though the directions of relative movement, or the operating forces, are already indicated by arrows.

As new textbooks appear, the newer developments of the growing science take their appropriate place amid the older, more familiar material. Secondary lineation, previously given little attention in general texts on structural geology, is here quite fully interpreted and its use in the field explained. Salt domes and granite tectonics are not so new. The chapter on structural petrology, introducing the methods of petrofabric analysis in simplified fashion, is likely to be appreciated by those geologists who desire some acquaintance with these methods but who thus far have regarded them as largely the property of specialists. The final chapter, "Geophysical Methods in Structural Geology," gives recognition to the important role which these methods now play in locating buried structures and in subsurface prospecting. In both of these comparatively technical chapters, as elsewhere in the book, clear thinking by the writer makes for clear understanding by the reader.

At the end of the book are laboratory exercises in 56 pages of finer print. Approved meth-

[1] *Amer. Jour. Sci.*, Vol. XXXI (1936), pp. 401–20.

ods (chiefly geometric and trigonometric) for solving structure problems, with good selections of practice problems to be worked out by the student, are presented under eleven headings.

Oversights are very few. Figure 163 is an admirable illustration of the genesis of a belt of echelon normal faults. However, the individual faults of the Lake Basin belt in Montana trend northeast-southwest, not "northwesterly," as stated on page 194; and consequently the statement on page 195, "This belt of faulting is due to a couple, the northerly block moving east relative to the southerly block, as in Fig. 163," is incorrect. It was the southerly block that moved east relatively in this Montana case.

Probably some geologists will miss the larger relations of earth deformation and the more theoretical aspects of tectonics which they have become accustomed to find in texts on structural geology, such as the development of stresses, isostasy, the nature of mountain-building, the evolution and behavior of continental masses, and so forth. But the author at the outset has given his reasons for not undertaking to bring in the more abstruse phases of the subject. These may be left to the instructor to introduce in his own way. Within the scope of the treatment the student will find that a great deal of the material is so well presented that he can grasp it quite satisfactorily from a careful study of the text alone. On the other hand, the instructor of advanced classes, besides hammering on principles and reinforcing with supplementary examples, will wish further to justify his part by bringing in plenty of new points and ideas that the student does not find in his textbook. So, with this new structural geology, the student obtains much of his instruction from his own study, while enough is left to the teacher to enable him to add strongly to the class discussions.

R. T. C.

Scott County Geology, Tests, Fossils. By HARLAN RICHARD BERGQUIST and THOMAS EDWIN MCCUTCHEON. (Mississippi State Geological Survey, Bull. 49.) University, Miss., 1942. Pp. 146; figs. 23; pls. 11.

Scott County Geology, Tests, Fossils is the most recent of the many excellent county reports of the Mississippi State Geological Survey. The bulletin is divided into three sections.

The section on "Geology," by Bergquist, contains a detailed account of the stratigraphy of Scott County. The Lisbon formation of the Claiborne Eocene group is the oldest formation represented. The Pliocene is unconformable upon the Vicksburg Oligocene, the contact recording extensive Miocene erosion. Two generations of terraces are recognized: the older, late Pliocene or early Pleistocene, and the younger, later Pleistocene. Several pages of test-hole records are also included.

"Scott County Tests," by McCutcheon, comprises the second section. In it the physical and chemical properties of the local clays are described, and a useful account of laboratory procedure, with an index, is included.

The third section, by Bergquist, describes the Jackson, Upper Eocene, Foraminifera, and Ostracoda. Although this report is not intended by the author to be a complete record of the state-wide Jackson microfauna, 225 species and 4 varieties are new, and 34 species and varieties are reported in the Jackson for the first time. The Ostracoda are represented by 17 species and 2 varieties. This section is illustrated with 11 plates and is indexed.

The bulletin also presents structural and geologic maps of Scott County.

IRVING B. HAMILTON

Ore Deposits as Related to Structural Features. Prepared under the direction of the Committee on Processes of Ore Deposition of the Division of Geology and Geography of the National Research Council. Edited by W. H. NEWHOUSE. Princeton, N.J.: Princeton University Press, 1942. Pp. 280; figs. 248. $6.50.

The world's ore deposits have been formed under a great diversity of conditions, and no single geologist can study in detail more than a few ore-bearing districts in a lifetime. Studies of individual districts have brought out certain principles, but these can be fitted into their proper places and their relative importance established only by comparative studies of a large number of ore occurrences. In particular, this committee on processes of ore deposition has felt the need for bringing together in orderly assemblage the interrelated facts of geologic structures and ore occurrences. This need the committee has endeavored to fill by preparing the present quarto volume. Its scope may be

gathered from the list of sixty-five different contributors who have covered the field very widely. Emphasis throughout has been placed on descriptions and facts rather than on theory.

The first chapter of 51 pages, "Some Relations of Ore Deposits to Structural Features," is a combined introduction and summary in three parts. B. S. Butler opens with the broader relations, introducing particularly the factor of depth (shear-zone deposits versus those along "breccia breaks" nearer the surface, and closeness to the surface of the source-magma penetration). T. S. Lovering follows with a clear discussion of the physical factors in the localization of ore. W. H. Newhouse, chairman of the committee, then outlines the whole subject at greater length from the point of view of structural geology.

The masterly treatment by Newhouse is, in a sense, the key to the volume, opening the way for the discussions of the many representative districts and classifying much of that factual information by structural relations. If it is invidious to single out the exposition of fault relations for special commendation, that is simply because a short review cannot do justice to this handling of a many-sided subject. Probably it will surprise some teachers of structural geology to perceive how much better their students might have been prepared for underground work on ore veins if they had given more specific attention to fault deviations and deflections. Besides very practical training in concrete fault behavior, they can give thereby also a fuller understanding of the principles of faulting. Newhouse's correlation of type of ore deposit with type of faulting is presented in detailed tabular form, followed by analytical discussions of the more pertinent facts and relationships. Taken up successively in similar fashion are the relations of ore deposits to folds, to rock types, and, finally, the occurrence of ore deposits at or near contacts of dissimilar rocks.

The major portion of the volume is devoted to descriptions, with requisite interpretations, of a large number of the world's most representative ore districts. As stated in the Preface: "Geologists who have had sustained and intimate contact with the ore occurrence in a mine or district were solicited for summary accounts of structural features as related to ore occurence." Their numerous contributions are arranged under the following headings: chapter ii, "Structural Features Associated with Ore Deposits of Certain Types and in Large Areas"; chapter iii, "Ore Deposits in Massive Rocks"; chapter iv, "Ore Deposits in Layered Rocks"; and chapter v, "Ore Deposits near Contact of Massive and Layered Rocks." Under these main headings the individual contributions (ore districts) are further classified in subordinate groups according to their structural features. As each district is succinctly and authoritatively treated, these summary accounts are invaluable individually while serving collectively to advance the general subject.

Chapter vi, "Structural Petrology Applied to Ore Deposits," is a concise statement by H. W. Fairbairn.

R. T. C.

Proceedings of the Eighth American Scientific Congress, Vol. IV: *Geological Sciences*. Washington: Department of State, 1942. Pp. 764.

The attention of geologists interested in South America, Central America, Mexico, and the West Indies should be called to this extremely valuable collection of papers presented before the Geological Section of the Eighth American Scientific Congress, which met in Washington, May 10–18, 1940. Of these, thirty-seven are in English, twenty in Spanish, three in Portuguese, and one in French. They are grouped under the following headings: "Paleozoic Formations and History"; "Mesozoic and Tertiary Formations and History"; "Mesozoic and Cenozoic Vertebrate Faunas and Floras"; "Tectonics, Igneous History, and Physiography"; "General Geology"; "Petroleum"; "Metalliferous Deposits"; and "Vulcanology."

Primarily, but not exclusively, the contributions are summary regional studies covering various phases of the geology of a large part of Latin America. As such, they are a veritable mine of sifted, up-to-date information.

R. T. C.

Among the articles to appear in early numbers of *The Journal of Geology* are the following:

Middle Ordovician of Central Pennsylvania. By G. MARSHALL KAY

Sources of Modern Sands in the Middle Rio Grande Valley, New Mexico. By GORDON RITTENHOUSE

Effect of Sedimentation on Floods in the Kickapoo Valley, Wisconsin. By STAFFORD C. HAPP

Nourishment of the Greenland Continental Glacier. By WILLIAM HERBERT HOBBS

Early Ordovician Strata along Fox River in Northern Illinois. By H. B. WILLMAN and J. NORMAN PAYNE

The System $NaAlSiO_4$-$CaSiO_3$-Na_2SiO_3. By JOSEPH SPIVAK.

FIJI: Little India of the Pacific

By JOHN WESLEY COULTER

"Colonel Coulter is highly qualified to furnish an authentic, well arranged account of his investigations in Fiji."—*The Military Engineer.*

"Colonel Coulter, formerly the head of the Geography Department in the University of Hawaii, has written an admirable little book which should be of considerable interest to the students of the problems of Indians abroad and the problems of the Pacific."—*Pacific Affairs.*

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Developing Map Reading Skills for Global Emphasis - - - - - - KENNETH A. FULLER
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